

A POTENTIOKINETIC DETERMINATION OF  
CORROSION RATES IN ARTIFICIAL SEAWATER-  
HYPOCHLORITE SOLUTIONS

Joseph Maurice Price

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## THESIS

A POTENTIOKINETIC DETERMINATION OF  
CORROSION RATES IN ARTIFICIAL SEAWATER -  
HYPOCHLORITE SOLUTIONS

by

Joseph Maurice Price

June 1976

Thesis Advisor:

Richard A. Reinhardt

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A Potentiokinetic Determination of Corrosion  
Rates in Artificial Seawater - Hypochlorite Solutions

by

Joseph Maurice Price  
Lieutenant Commander, United States Navy  
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Submitted in partial fulfillment of the  
requirements for the degree of

MASTER OF SCIENCE IN PHYSICS

from the

NAVAL POSTGRADUATE SCHOOL  
June 1976



## ABSTRACT

The corrosion rates of various metal alloys in artificial seawater and artificial seawater-CLOROX solutions was determined potentiokinetically employing the cathodic overvoltage-intercept method. The results obtained in the artificial seawater system agreed quite well with those obtained from previous ocean immersion tests. With the exception of an aluminum alloy, the effect of the addition of CLOROX was the same for all materials with the corrosion potential becoming more positive and the alloy less resistant to corrosion.



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## LIST OF SYMBOLS

$\beta$	Tafel slope
$e$	equivalent weight
$e^-$	electron
$E$	cell potential (volts)
$E_{\text{corr}}$	corrosion potential (volts)
$E_O^\circ$	standard electrode potential oxidation half-reaction
$E_R^\circ$	standard electrode potential reduction half-reaction
$F$	Faraday's constant (96,500 coulombs)
$G$	change in Gibbs Free Energy Function
$j$	current density ( $\mu\text{A}/\text{cm}^2$ )
$j_{\text{corr}}$	corrosion current density ( $\mu\text{A}/\text{cm}^2$ )
$\log$	decimal logarithm
$M$	metal
$M^{n+}$	metal ion
mil	.001 inch
$N$	normal (equivalent weight/liter)
ppm	parts per million (mass ratio)
$R_{\text{corr}}$	corrosion rate
$R_{\text{mmpy}}$	corrosion rate in mm/year
$R_{\text{mpy}}$	corrosion rate in mils/year
SCE	saturated calomel electrode
SiC	silicon carbide
$[\text{OCl}^-]$	hypochlorite ion concentration
$\text{OCl}^-$	hypochlorite ion



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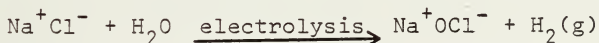


## I. INTRODUCTION

### A. BACKGROUND

The problems of corrosion and fouling are primary considerations in the design of ships and marine installations. In the internal seawater systems of ships and marine power stations, where heat transfer and long service life are critical, the common anti-fouling and corrosion prevention procedures, e.g., anti-fouling paints, increased wall thickness of piping and tubes, corrosion- and fouling-resistant alloys, etc., may actually reduce the heat transfer capabilities of the system, and most assuredly will increase the cost of fabrication. Therefore, if more efficient heat transfer systems are to be constructed, these corrosion problems will have to be better understood, thus providing for a more intelligent selection of materials.

One novel solution proposed for the fouling problem is to treat the incoming seawater with the hypochlorite ion, either by the addition of a sodium hypochlorite ( $\text{NaOCl}$ ) solution or by on-site electrolysis of saline water to produce  $\text{NaOCl}$ .



A device to introduce the hypochlorite ion in this latter manner is currently manufactured and marketed by Engelhard Industrial Division of Engelhard Minerals and Chemical Corporation under the trade name of CHLOROPAC.



It is commonly accepted that 0.5 parts per million (ppm) of chlorine in the form of the hypochlorite ion ( $9.7 \times 10^{-6}$  N) will control mollusk growth in seawater systems. [1] ,[2]. The recommended operating procedures for the CHLOROPAC are designed to provide this low concentration (0.5 ppm) in the areas where fouling is to be controlled; near the generator, however, the  $\text{OCl}^-$  concentration may be as high as 100 ppm ( $2.0 \times 10^{-3}$  N) [2].

The ability of dilute NaOCl solutions to control the growth of marine life has been demonstrated in many industrial applications. The CHLOROPAC system was evaluated in an inservice test by the British Ship Research Association (BSRA) from May 1973 through September 1973. The BSRA report concluded that the CHLOROPAC system successfully prevented the growth of marine fouling with no increase in the corrosion of the seawater systems that could be attributed to the hypochlorite ion concentration [2]. However, during the BSRA evaluation, no attempt was made to measure the extent of corrosion or corrosion rate in either the seawater or seawater hypochlorite environments. A search of the literature resulted in a wide range of reported corrosion rates for the same metals in natural seawater. These values were determined in various locations and under various and nonreproducible conditions.

It is the intent of this thesis to determine by potentiodynamic methods the corrosion rate of selected metals with marine applications in an environment of synthetic seawater





and to compare these rates with those obtained in a synthetic seawater-sodium hypochlorite solution

## B. CORROSION PHENOMENA

Any number of paradoxical and complicated examples of the corrosion process can be and have been described. U. R. Evans suggested that "Possibly it is the strangeness of corrosion reactions which cause the orthodox physical chemist to regard the whole subject with suspicion" [3]. In the language of the electrochemist or corrosion scientist, the anode is often referred to as the active electrode and the cathode as the noble electrode. Corrosion, if defined as metal loss from the solid state, occurs at anodic areas, which exist at areas of lower electrode (reduction) potential within the cell. In all cases the oxidation-reduction reactions can be represented algebraically as:

$$\sum_Y \nu_Y M_Y \pm ne^- = 0$$

where  $\nu_Y$  is the number of formulas (or moles) in the balanced equation;

$M_Y$  is the chemical species;

and  $ne^-$  is the number of free electrons.

Thermodynamics provides information about the feasibility of a given net electrochemical cell reaction to take place, from the change in the Gibbs Free Energy Function ( $\Delta G$ ); the more negative the value of  $\Delta G$ , the greater the tendency for the reaction to take place [4]. For electrochemical reactions:



$$\Delta G = -nFE^\circ$$

where n is the number of electrons involved in the reaction;

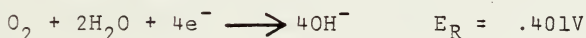
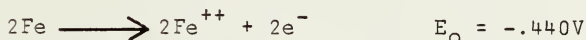
F is Faraday's Constant, 96500 coulombs/equivalent;

$E^\circ$  is the reversible cell potential.

The cell potential is determined from those for the separate oxidation and reduction half-cell reactions. For example, the corrosion of iron (Fe) in aerated seawater is:



separating this reaction into its anodic and cathodic half cell reactions:



$$E^\circ = .401\text{V} - .440\text{V} = .841\text{V}$$

Since  $E^\circ$  is positive,  $\Delta G$  is negative and the reaction is feasible.

Although the change in the Gibbs Function can tell if corrosion is possible, it cannot predict the corrosion rate ( $R_{\text{corr}}$ ). The corrosion rate is determined by the current flowing between the anode and cathode. In accordance with Ohm's law, this current is equal to the difference between the anode and cathode potentials divided by the total resistance of the circuit. When current flows between the anode and cathode, the potentials of both change. This change is called polarization [6].



The object of polarization experiments is to determine a steady state corrosion current density ( $j_{\text{corr}}$ ) and then calculate a corrosion rate assuming uniform or general corrosion. From Faraday's law the corrosion rate can be determined by the relationship:

$$R_{\text{corr}} = k j_{\text{corr}} e / \rho$$

where:

$\rho$  is the density of the metal corroding ( $\text{g/cm}^3$ ),

$e$  is the equivalent weight of the metal (g),

$j_{\text{corr}}$  is the corrosion current density ( $\mu\text{A/cm}^2$ ),

$k$  is a constant that includes Faraday's constant and the conversion factors required to obtain the desired units of length and time [6].

Therefore:

$$R_{\text{corr}}(\text{in mils/year}) = .1287 j_{\text{corr}} e / \rho$$

and

$$R_{\text{corr}}(\text{in mm/year}) = .003270 j_{\text{corr}} e / \rho$$

The current accepted units for penetration corrosion rates are mils/year.



TABLE I  
EMF SERIES [5]

<u>REDUCTION HALF REACTIONS</u>	<u>STANDARD REDUCTION POTENTIAL (volts)</u>
$\text{Hg}^{++}(\text{aq}) + 2\text{e}^{-} = 2\text{Hg}(\text{l})$	0.788
$\text{O}_2 + 2\text{H}_2\text{O} + 4\text{e}^{-} = 4\text{OH}^{-}$	0.401
$\text{Cu}^{++}(\text{aq}) + 2\text{e}^{-} = \text{Cu}(\text{s})$	0.337
$2\text{H}^{+}(\text{aq}) + 2\text{e}^{-} = \text{H}_2(\text{g})$	0.000
$\text{Ni}^{++}(\text{aq}) + 2\text{e}^{-} = \text{Ni}(\text{s})$	-0.250
$\text{Fe}^{++}(\text{aq}) + 2\text{e}^{-} = \text{Fe}(\text{s})$	-0.440
$\text{Zn}^{++}(\text{aq}) + 2\text{e}^{-} = \text{Zn}(\text{s})$	-0.763
$\text{Al}^{+++}(\text{aq}) + 3\text{e}^{-} = \text{Al}(\text{s})$	-1.662
$\text{Na}^{+}(\text{aq}) + \text{e}^{-} = \text{Na}(\text{s})$	-2.714





## II. EXPERIMENTAL PROCEDURES

### A. THE PROBLEMS OF DIRECT METHODS OF DETERMINING CORROSION RATES IN SEAWATER

Corrosion rates in seawater have commonly been determined by mounting metal coupons on a wood or metal rack and immersing the rack into the ocean, then measuring the weight loss or penetration directly [7,8,9,10,11]. This method is time consuming and expensive. The rack must be designed and constructed to avoid the following disturbing factors:

1. Galvanic action between different specimens or between the rack and specimens.
2. Local shielding of any appreciable area of a test piece so as to provide an opportunity for concentration cell corrosion.
3. Non-uniform flow of water past surfaces of different specimens.
4. Corrosion-accelerating or inhibiting effects of corrosion products from the rack material.
5. Abrasion of loose specimens due to rubbing against their supports.
6. Mechanical damage by floating objects.
7. Loss of the specimens due to rack failure.

To further compound the problem, materials to be compared directly should be exposed for the same length of time, since the growth of fouling organisms is seasonally dependent and



causes seasonal variations in the corrosion rates. The immersion tests normally take from six months to three years to perform. In addition to the above complexities, the researcher is unable to control the environment of the test specimens. Since most test sites are near shore, the composition of the seawater and local pollutants, and velocity across the specimens is variable and location dependent. As a result, corrosion rates obtained in this manner vary considerably from site to site [7]. In an attempt to alleviate some of these problems, a laboratory potentiokinetic method of determining corrosion rates was evaluated in this study. The aim was to determine the ability of this method to predict from laboratory evaluations in artificial seawater the corrosion rates which would result due to immersion testing in natural seawater.

#### B. POTENTIOKINETIC DETERMINATION OF CORROSION CURRENT DENSITY

Faraday's Law shows that the rate of metal converted to metal ion is proportional to the current transferred within a corrosion cell. Therefore, the determination of a general or uniform corrosion rate rests upon determining the current density associated with the corrosion potential. If the electrolyte is sufficiently stirred to prevent concentration polarization and the distance between the working and reference electrodes is small or the current is small so that the IR drop between these electrodes is insignificant, then the potential can be related to the current density by the Tafel



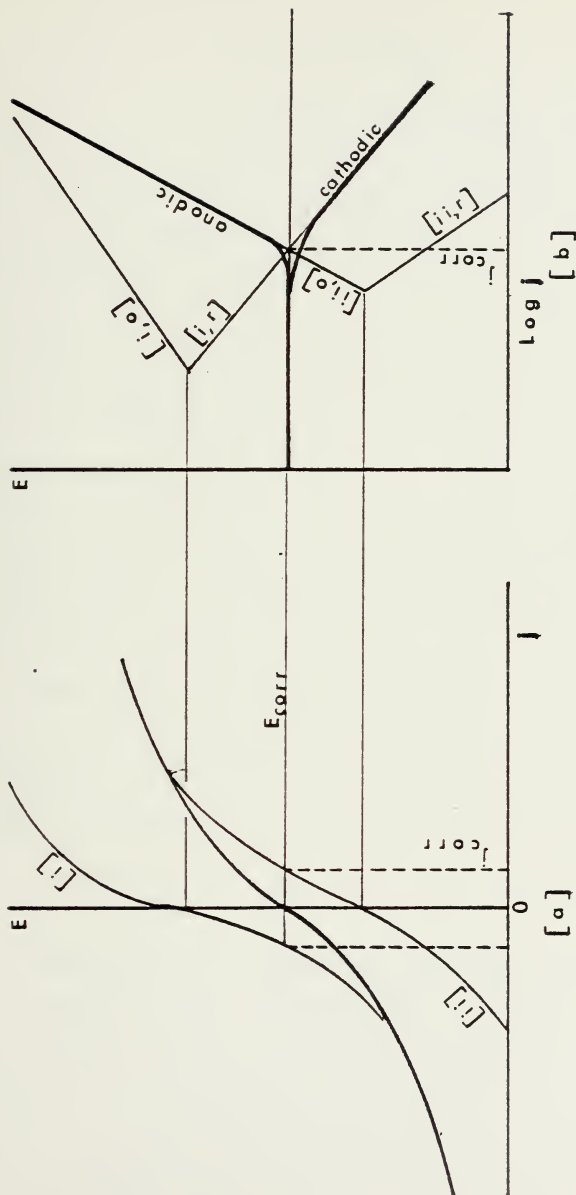
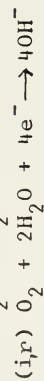
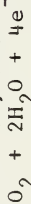
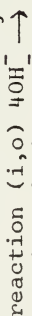


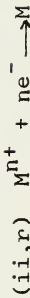
Figure 1. Anodic and cathodic polarization curves showing corrosion potential and current density.

[a] Linear current density scale



[b]

Logarithmic current density scale





Law [4,12]. The Tafel Law can be expressed either by:

$$E = \alpha + \beta \log(j)$$

or

$$E - E_{\text{corr}} = \beta \log(j/j_{\text{corr}})$$

where  $\beta$  is the anodic or cathodic Tafel slope and like  $E_{\text{corr}}$  and  $j_{\text{corr}}$  is dependent upon the nature of the electrode and its environment. Ideally when potential vs current density is plotted semilogarithmically for various values of  $E$  and  $j$ , the anodic and cathodic curves will obey the Tafel relationship at a distance from  $E_{\text{corr}}$  and become curved and asymptotic to  $E_{\text{corr}}$  as  $E$  approaches  $E_{\text{corr}}$  (Figure 1). Then by extending the Tafel slopes to intersect the horizontal representing  $E_{\text{corr}}$ , it should be possible to determine the corrosion current density. This method is referred to as the overvoltage-intercept method [13,14]. As can be seen from Figures 11 through 32, the actual experimental curves obtained do not always have a readily identifiable Tafel slope. This was particularly true for the anodic curves in this study. The cathodic slope was determined in the region [14]:

$$E_{\text{corr}} - 0.05V \leq E \leq E_{\text{corr}} - 0.20V.$$

Experimentally it has been determined that the best value for the corrosion current density can be obtained by extending the cathodic slope to intersect with the corrosion potential [13,14]. This apparent discrepancy can be partially attributed to the fact that the anodic reactions are not uniformly distributed over the surface of the specimen, therefore the





area used in calculation of  $j_{\text{anodic}}$  may be in error [13]. It is also conceivable that a number of oxidation-reduction reactions are occurring at potentials above  $E_{\text{corr}}$ , whereas, at lower potentials the reduction of oxygen predominates [12]. In any case, the cathodic overvoltage-intercept method was applied in this study because the expense in setting up the experiments was minimal and results could be obtained in a matter of hours vice months.

### C. CHOICE OF CORROSIVE MEDIUM

Seawater is a complex, delicately balanced solution of many salts containing living matter, suspended silt, dissolved gases, and decaying organic matter. An individual effect of each of these components affecting the corrosion behavior of the system is not readily separated. The major factors which can be identified as effecting corrosion rates are:

1. Dissolved oxygen content
2. Biological activity
3. Temperature
4. Velocity
5. Salinity
6. pH
7. Chemical composition [16].

In order to develop a standard procedure and reduce the number of uncontrollable factors, a standard electrolyte was necessary. To avoid the effects of organic matter and biological activity, local Monterey Bay water was not used.



Standard seawater from the IAPSO Standard Sea-Water Service, Charlottenlund, Denmark, was not used because the quantity required was cost-prohibitive. Therefore, a laboratory substitute was desirable. Initially, a .6N solution of sodium chloride was considered. However, a search of the literature showed that where this solution was substituted for seawater, the resulting corrosion rates were generally higher than those obtained in seawater and that the disparity was time dependent [17]. The ultimate choice of electrolyte was the formula and procedure developed by Kester, et al [18] and described in Appendix A. This formula closely reproduces the composition of standard seawater and could be made relatively inexpensively in the quantity required. After the artificial seawater was prepared, its conductivity and pH were compared with a standard sample.

The desired hypochlorite ion concentration was obtained using CLOROX additions. A new bottle of CLOROX was first standardized by iodimetry and the hypochlorite ion concentration determined to be 0.45807N [19]. The desired concentration of the hypochlorite ion was then calculated in terms of a volume of CLOROX and added to the measured amount of seawater. For example, in order to obtain a hypochlorite concentration of 100 ppm in 2kg of seawater, the following calculations were required:

1. 100 ppm  $[\text{OCl}^-]$  = .2g  $\text{OCl}^-$ /2kg seawater
2. Molecular weight of  $\text{OCl}^-$  = 16.000 + 35.457 = 51.457
3. Number of moles required = .2g/51.457g/mole =  
3.887 mmoles



4. Volume of CLOROX to be added to 2kg seawater  
= 3.887 mmoles/.45807 moles/liter  
= 8.4856ml.

Therefore, 8.49ml of CLOROX was pipetted into 2kg of seawater to produce a hypochlorite concentration of approximately 100 ppm.

#### D. METAL ELECTRODES

The metal alloy samples from which the electrodes were manufactured were provided by Mare Island Naval Shipyard, Laboratory Division, and are representative of the alloys used in ship construction. The chemical composition of the samples, their density and equivalent weights are given in Appendix B.

The samples were cut and machined to 0.500 in (1.27 cm) diameter and cut to a length of .375 in (0.95 cm). Each electrode was drilled and tapped to facilitate mounting on an electrode holder (Figure 2). Before being mounted on the electrode holder, the specimens were first mounted on a short length of 1/2 inch wood doweling with sealing wax (Figure 3) and polished on a lathe with various grades of SiC paper, finishing with 600 grit SiC paper. The samples were then placed in a test tube, covered with benzene, and placed in an ultrasonic bath for approximately ten minutes to clean the surfaces. The samples remained in the benzene until just prior to mounting, but no longer than three hours. Before assembling the working electrode, the specimen was placed in a 50 ml erlenmeyer flask filled with distilled water, stoppered





Figure 2. Specimens, electrode holder  
and teflon washer prior to assembly.







Figure 3. Specimen and dowel  
assembled for polishing.



and returned to the ultrasonic bath and rinsed for about one minute. The sample was then dried, the top coated lightly with stopcock grease and threaded on the electrode holder. The teflon washer spaced between the sample and the glass tubing sealed the end of the tube and was cut in such a manner to position the salt bridge probe 1.778 mm from the sample. The area of the corroding surface was approximately  $5 \text{ cm}^2$ .

Two platinum auxiliary electrodes were prepared from high purity sheet stock with dimensions 1.28 cm by 1.768 cm for a surface area of  $4.53 \text{ cm}^2$ . The platinum electrodes were then platinized and stored in distilled water until required for use. Frequent cleaning and replatinizing of the surfaces were required during the period of the experiment.

#### E. EQUIPMENT

The equipment used to determine the corrosion current densities was:

1. TRW Instruments Model 200A Research Potentiostat
2. Hewlett-Packard Mosely 136A X-Y Recorder
3. Precision Scientific Co. Magnamix magnetic stirrer and stirring bar
4. 2 liter resin kettle heating mantle
5. 2 liter reaction flask (resin kettle) and cover
6. 100 ml three necked flask
7. Heating mantle for a round bottom flask
8. Saturated calomel electrode (SCE)
9. Salt bridge



10. Thermometers; 0° to 50 °C range, 2
11. General Radio Company Variac Autotransformers, 2
12. Weston Model 1240 Digital Multimeter
13. Seven (7) receptacle outlet box
14. Constant voltage isolation transformer
15. Leeds and Northrup Company Temperature Potentiometer
16. Platinum auxiliary electrode
17. Metal sample working electrode

The complete experimental arrangement is shown in Figure 4. The three electrodes were connected to the potentiostat in accordance with the technical manual and illustrated in Figure 5. The grounds were lifted on the recorder, multimeter and stirrer before these units were connected to the outlet box. This was necessary to avoid introducing stray currents into the potentiostat. The potentiostat and resin kettle heating mantle Variac were also connected to the outlet box, and the outlet box was connected to the isolation transformer. The heating mantle for the reference cell was connected directly to the bench electrical supply.

The corrosion cell consisted of a two-liter reaction flask which contained two kilograms of artificial seawater and the required amount of CLOROX. The electrodes, salt bridge probe and thermometer were arranged as shown in Figure 6. The salt bridge probe was positioned to "look" at the working electrode without blocking the current path from the platinum auxiliary electrode. The salt bridge probe was maintained at a distance of 1.778 mm from the working



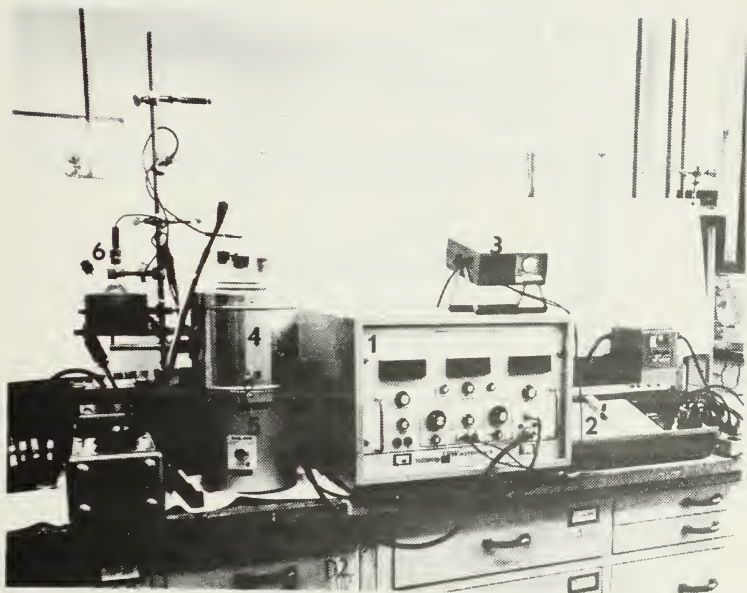


Figure 4. Experiment Equipment Arrangement

- |                       |                     |
|-----------------------|---------------------|
| 1. Potentiostat       | 4. corrosion cell   |
| 2. X-Y Recorder       | 5. Magnetic stirrer |
| 3. Digital multimeter | 6. Reference cell   |





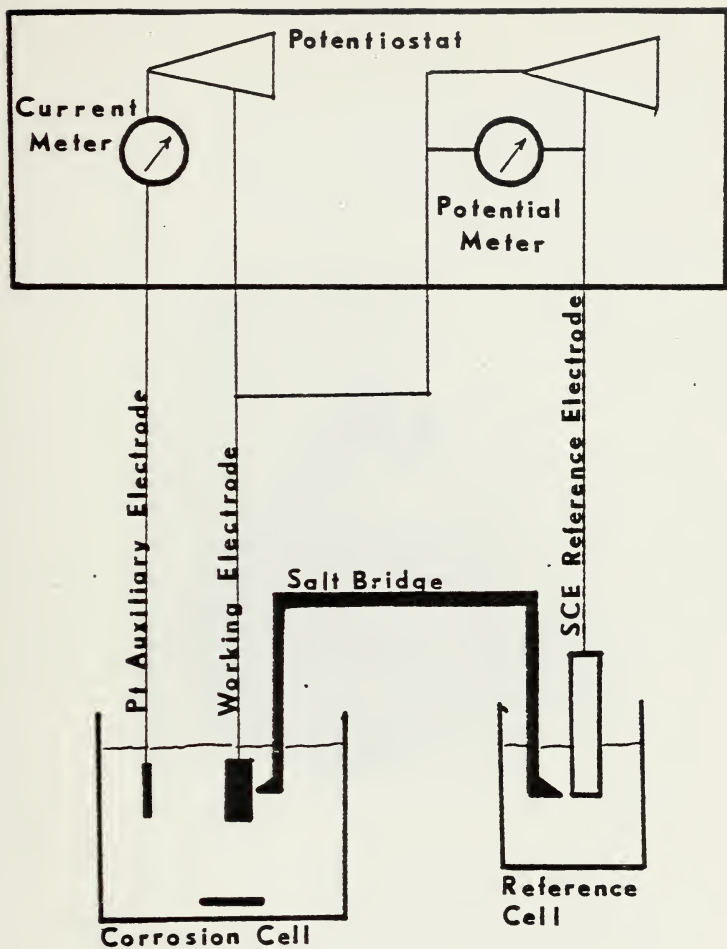


Figure 5. Electrode connections to potentiostat.



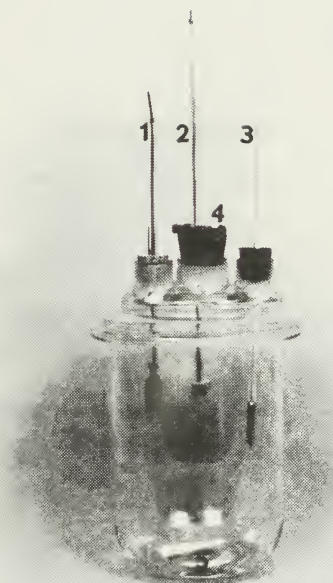


Figure 6. Corrosion cell assembly

- (1) Reference electrode
- (2) Working electrode
- (3) Thermometer
- (4) Salt bridge probe
- (5) Stirrer



electrode surface by fitting the tip of the probe into a notch cut into the teflon washer and adjusting a screw type hose clamp located above the rubber stopper and between the working electrode and the salt bridge probe. A magnetic stirring bar was placed in the cell and the cell placed within the resin kettle heating mantle (Figure 7).

The reference cell consisted of a 100 ml three-necked flask filled with saturated potassium chloride (KCl) solution with a saturated calomel electrode (SCE) fitted in the center neck. The salt bridge probe and thermometer were fitted into the remaining necks.

The salt bridge was constructed from two disposable Pasteur pipettes with the tips bent at right angles and cut to the desired length. These probes were then filled with a hot saturated KCl-Agar solution and cooled. The two probes were connected with Tygon tubing and a glass "T". The tubing was then filled with saturated KCl through the "T" and the "T" then stoppered. This arrangement allowed the salt bridge to flex as required during the replacement of electrodes and electrolyte.

The current and potential measuring outputs of the potentiostat were connected to the X and Y axes respectively. The X axis of the recorder was scaled by the output of the Leeds and Northrup temperature potentiometer. The Y axis was scaled with the potential output of the potentiostat. The calibration of the recorder was checked frequently during the experiment and the recording annotated with the



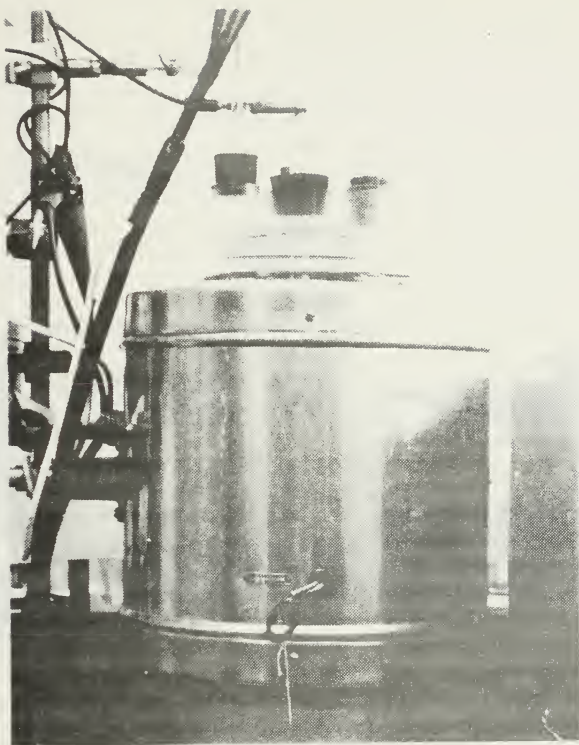


Figure 7. Corrosion cell assembly  
in heating mantle.





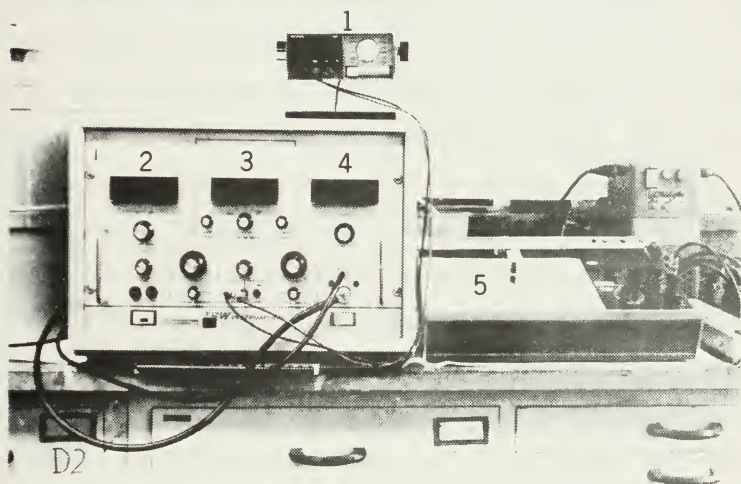


Figure 8. Information displays

- (1) Digital multimeter (potential)
- (2) Voltmeter
- (3) Potential meter
- (4) Current meter
- (5) X-Y recorder (potential vs current)



with the meter values. The potential setting was monitored with the Weston digital multimeter which allowed accurate determination of the potential to within one millivolt (Figure 8).

#### F. EXPERIMENTAL PROCEDURES

The operation of the potentiostat was in accordance with the procedures contained in the technical manual. The reference cell and corrosion cell were first brought up to the temperature of 25 °C. The corrosion cell Variac was de-energized after the cell reached 25 °C to reduce electrical interference. The resin kettle heating mantle nearly enveloped the corrosion cell and was able to maintain the temperature for over one hour. The mantle also partially screened the cell from electrical interference. The equipment was so sensitive to electrical interference that before measurements were begun, all fluorescent lamps in the vicinity were extinguished. Then the calculated volume of CLOROX was added to the cell and the electrolyte solution was stirred. The working electrode was assembled and immersed into the electrolyte and the cell allowed to stand on open circuit for fifteen minutes. During this period the hypochlorite ion concentration was determined by iodimetry. For runs without the addition of hypochlorite, 0.1 g of sodium thiosulfate per 2 kg seawater was added to prevent the formation of hypochlorite ion by the electrolysis in the seawater.

After the fifteen minute time period, the open circuit potential was measured, the cell potential was then preset



0.6 V below the open circuit potential and the cell was energized. The cell potential was then manually scanned at a rate of 1 mV/sec in the noble direction until the indicated cell potential was .5 V above the measured corrosion potential. Upon completion of one scan, the working electrode was exchanged and the process repeated. At the end of the second scan the cell was removed from the mantle and the electrolyte hypochlorite ion concentration was determined. The electrolyte was renewed after every other scan. The corroded surface area was measured by a dial caliper.

#### G. PROBLEMS

As with any piece of equipment that has not been exercised for any period of time, the potentiostat required extensive rehabilitation and realignment. All power transistors and many resistors of the heat sink required replacing before the potentiostat would operate. Then, in order to align the unit, all vacuum tubes on the current amplifier board was replaced. During the experiment, these same tubes were replaced twice again.

Initially, it was intended to plot log (current) versus potential. However, the logarithmic amplifier was not compatible with the potentiostat and had to be disconnected from the system.

The early trials showed a great disparity in the corrosion potential and current densities obtained in successive scans in the same electrolyte. It was then determined that the electrolysis of the electrolyte was producing a



significant concentration of hypochlorite ion. It was empirically determined that 0.1 g of the reducing agent, sodium thiosulfate, precluded the development of a measurable concentration of the hypochlorite ion for at least three successive scans. To insure that the hypochlorite ion concentration increase would not be a significant problem, only two scans were made in the electrolyte before renewal. Similar considerations limited the use of the hypochlorite-seawater systems to two successive scans.

An additional and uncontrollable complication was the interference in the system caused by stray high frequency electrical noise, especially a tone associated with the IBM terminal located on the second deck of Spanagel Hall. When this tone was generated, the recorder circuit was saturated and the potentiostat was de-energized. If the duration of the noise was long enough, the trial was abandoned, causing a loss of time and materials. Most of the 60 Hz electrical noise was, however, effectively screened out by the isolation transformer and the heating mantle.

Finally, during the last week of experimentation, the Model 136A recorder failed and was replaced with the Model 7035B recorder.





### III. PRESENTATION OF DATA

#### A. PREPARATION OF DATA FOR ANALYSIS

The data generated during each experimental run were recorded directly as potential vs current (Figure 9) on a Hewlett-Packard X-Y recorder. Because of the range of current required to reach and maintain the desired potentials, the potentiostat current range scale was shifted at each decade to provide greater precision in determining the current associated with a particular potential. Next, a convenient interval was chosen on the potential axis and the associated current value identified. The area of the corroded surface of the sample was measured and the current density then computed. A summary of data is presented in Appendix C.

The  $E$  vs  $\log(j)$  points were plotted on the WANG 720C Computer. A third-order curve was drawn separately through the anodic and cathodic points in an effort to assist in identifying the Tafel (linear) region of each curve (Figure 10). With the aid of these curves, the anodic and cathodic Tafel slopes were extended to intersect the measured corrosion potential. The intersection of the cathodic Tafel slope and  $E_{\text{corr}}$  determined the corrosion current density ( $j_{\text{corr}}$ ). Figures 11 through 32 illustrate this procedure. Table II lists the corrosion current density and corrosion potential for each trial.



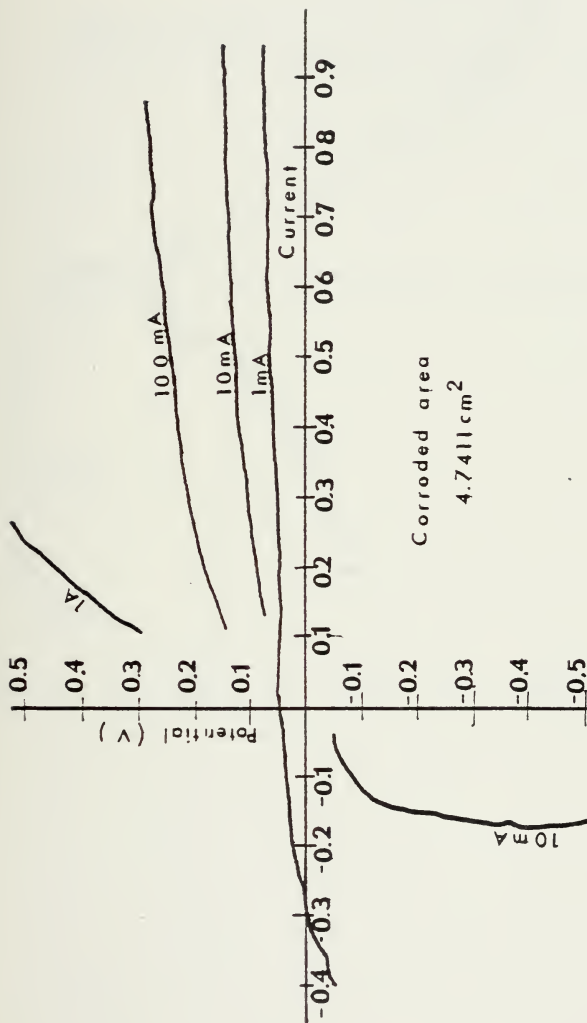


Figure 9. Potential vs Current, nickel in seawater.



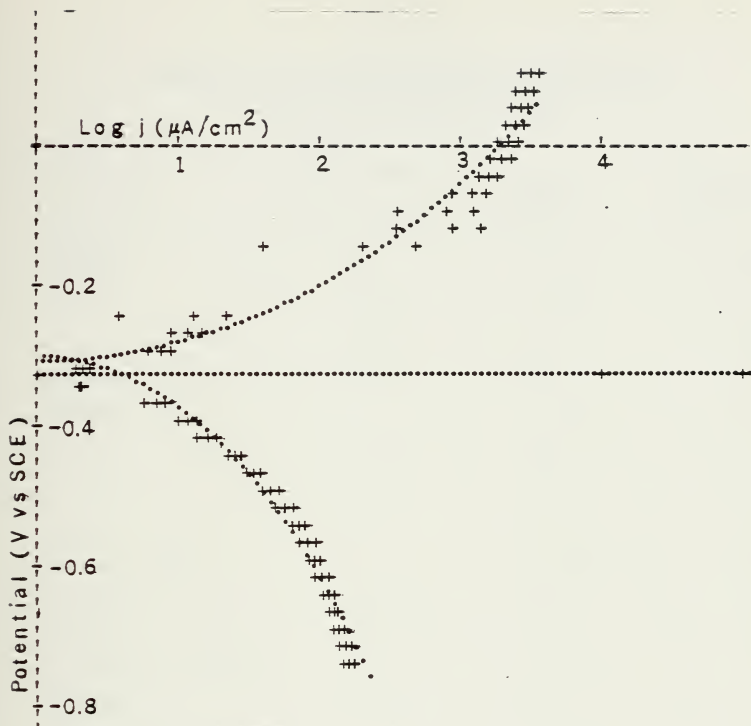


Figure 10. Third order regression analysis - nickel in seawater.



TABLE II  
SUMMARY OF ELECTROCHEMICAL INFORMATION  
FOR EXPERIMENTAL TRIALS

<u>Specimen</u>	<u>[OCl<sup>-</sup>] (ppm)</u>	<u>j<sub>corr</sub> (<math>\mu</math>A/cm<sup>2</sup>)</u>	<u>E<sub>corr</sub> (V vs SCE)</u>
Copper	0	5.75	-.266
	33.69	64.56	-.174
	56.38	457.8	-.101
	89.65	239.9	-.059
Nickel	0	3.311	-.338
	26.24	66.07	.062
	53.78	93.33	-.009
	108.5	31.62	.033
Naval Brass	0	7.762	-.287
QQ-B-637	93.29	66.07	-.132
Phosphor Bronze	0	10.96	-.236
QQ-B-750	108.5	120.2	-.071
Copper Nickel	0	3.020	-.288
Mil-C-15726E	102.2	100.0	-.010
K-Monel	0	5.495	-.300
Alloy K-500	88.85	26.92	.077
Steel Alloy	0	83.18	-.520
HY-80	104.5	354.8	-.335
Stainless Steel	0	.4365	-.211
Alloy 304	99.31	4.073	.125
Aluminum	0	58.88	-.793
Alloy 7075	96.82	12.59	-.757





## B. DETERMINATION OF CORROSION RATES

Table III gives the corrosion rates in millimeter/year ( $R_{\text{mmpy}}$ ) and mils/year ( $R_{\text{mpy}}$ ) determined from

$$R_{\text{corr}} = k_e j_{\text{corr}} / \rho$$

These are compared to the values for  $R_{\text{mpy}}$  found in the literature for the metal specimens in seawater. The values quoted in the literature are for metal coupons completely immersed in the oceans at various depths. The values for  $R_{\text{mpy}}$  determined from the present work fall within the upper range of the reported values, with the exception of those determined for phosphor bronze, aluminum alloy 7075 and steel alloy HY-80.

The experimentally determined corrosion current densities in artificial seawater and hypochlorite ion solution and the resulting corrosion rates are given in Table IV.

With the exception of Aluminum Alloy 7075, all corrosion rates increased at least one order of magnitude with the addition of approximately 100 ppm  $\text{OCl}^-$  to the artificial seawater. The corrosion rate for Aluminum Alloy 7075 decreased to approximately one quarter of the corrosion rate in the untreated seawater.

The following symbols are used in Figures 11 through 32:

(1)  $++$  representing the mean value and standard deviation for those trials with four or more runs.

(2) O,X for those trials consisting of duplicate runs, O represents the first run and X the second.



TABLE III

COMPARISON OF CORROSION RATES IN SEAWATER  
DETERMINED FROM PRESENT WORK WITH PREVIOUSLY MEASURED VALUES

<u>Metal</u>	<u>Location</u>	<u>R<sub>mpy</sub></u>
1. <u>COPPER</u>		
Present work	$R_{mpy} = 6.69 \times 10^{-2}$	2.63
Reinhart, et al [8]	Port Hueneme, Ca	0.9 1.1 1.2
NRL [11]	Key West, Fla	0.37
Uhlig [7]	Bristol Channel	2.8 2.7
	Bridgeport, Ct	2.4 2.0
	Eastport, Me	0.4
	San Francisco, Ca	4.0
	Kure Beach, N.C.	1.4 1.5 1.6 1.7
2. <u>NICKEL</u>		
Present work	$R_{mpy} = 3.59 \times 10^{-2}$	1.41
Reinhart, et al [8]	Port Hueneme, Ca	6.9 4.5 1.9 1.5
Fontana and Greene [5]		1.0



Table III Nickel (Cont.)

Uhlig [7]	Bridgeport, Ct	0.8
	Bristol Channel	0.3
	San Francisco, Ca	1.2
	Kure Beach, N.C.	1.0 0.7
3. <u>NAVAL BRASS</u>		
Present Work	$R_{mmpy} = 9.89 \times 10^{-2}$	3.89
NRL [11]	Key West, Fla	0.26
Uhlig [7]	Bristol Channel	4.3
		0.6
		1.7
		1.8
4. <u>PHOSPHOR BRONZE</u>		
Present Work	$R_{mmpy} = .133$	5.25
Reinhart, et al [8]	Port Hueneme, Ca	1.1
		1.3
Uhlig [7]	Kure Beach, N.C.	0.8 1.2
5. <u>COPPER NICKEL</u>		
Present Work	$R_{mmpy} = 3.49 \times 10^{-2}$	1.37
Reinhart, et al [8]	Port Hueneme, Ca	0.3
		0.4
NRL [11]	Key West, Fla	0.07
Uhlig [7]	Kill-van-Kull, N.J.	1.5
	Cape May, N. J.	0.5
	Kure Beach, N.C.	0.3
6. <u>K-MONEL</u>		
Present Work	$R_{mmpy} = 6.12 \times 10^{-2}$	2.41



Table III K-Monel (Cont.)

Reinhart, et al [8]	Port Hueneme, Ca	3.6
Uhlig [7]	Eastport, Me	1.2
	San Francisco, Ca	2.4
	Kill-van-Kull, N.J.	1.2
	Cape May, N.J.	1.7
	Kure Beach, N.C.	0.3
7. <u>HY-80 STEEL</u>		
Present Work	$R_{mmpy} = .960$	37.8
Schreir [12]	Approximate value	4 to 14
8. <u>STAINLESS STEEL</u>		
Present Work	$R_{mmpy} = 4.78 \times 10^{-3}$	.188
Reinhart, et al [8]	Port Hueneme, Ca	0.4 0.5 0.7 1.2
NRL [9]	Tongue of the Ocean	0.24
9. <u>ALUMINUM 7075</u>		
Present Work	$R_{mmpy} = .757$	29.8
NRL [10]	Key West, Fla	11 to 20





TABLE IV

POTENTIOKINETICALLY DETERMINED VALUES OF CORROSION  
RATES IN ARTIFICIAL SEAWATER

<u>Metal</u>	<u>[OCl<sup>-</sup>] ppm</u>	<u>i<sub>corr</sub> (μA/cm<sup>2</sup>)</u>	<u>R<sub>mpy</sub></u>	<u>R<sub>mmpy</sub></u>
Copper	0	5.75	2.63	6.69 × 10 <sup>-2</sup>
	34.69	64.56	29.5	.752
	56.37	457.8	210.0	5.32
	89.65	239.9	110.0	2.79
Nickel	0	3.311	1.41	3.59 × 10 <sup>-2</sup>
	26.24	66.07	28.2	.716
	53.77	93.33	39.79	1.01
	108.5	31.62	13.48	.342
Naval Brass	0	7.762	3.89	9.89 × 10 <sup>-2</sup>
	93.29	66.07	33.1	.842
Phosphor Bronze	0	10.96	5.25	.133
	108.5	120.2	57.6	1.46
Copper-Nickel	0	3.020	1.37	3.49 × 10 <sup>-2</sup>
	102.2	100.0	45.41	1.15
K-Monel	0	5.495	2.41	6.12 × 10 <sup>-2</sup>
	88.85	26.92	11.8	.300
HY-80 Steel	0	83.18	37.8	.960
	104.5	354.8	161.2	4.09
Stainless Steel	0	.4365	.188	4.78 × 10 <sup>-3</sup>
	99.31	4.073	1.75	4.45 × 10 <sup>-2</sup>
Aluminum 7075	0	58.88	29.8	.757
	96.82	12.59	6.37	.162



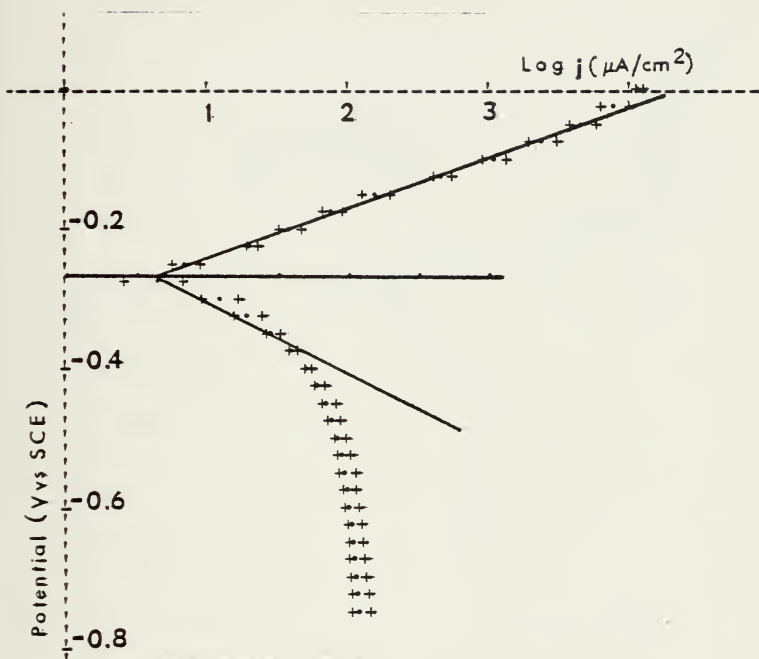


Figure 11. Copper in untreated seawater.



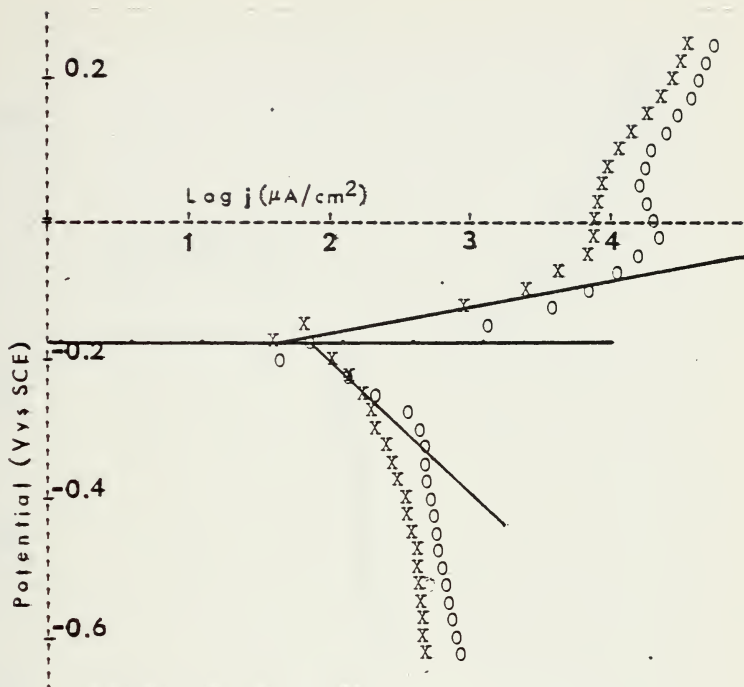


Figure 12. Copper in seawater  
treated with 34.69 ppm  $\text{OCl}^-$



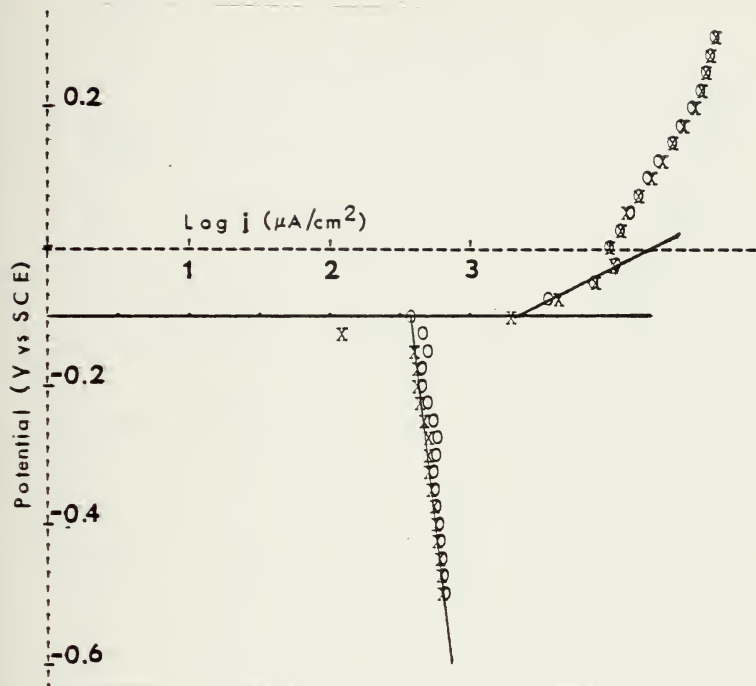


Figure 13. Copper in artificial seawater  
treated with 56.37 ppm  $\text{OCl}^-$ .





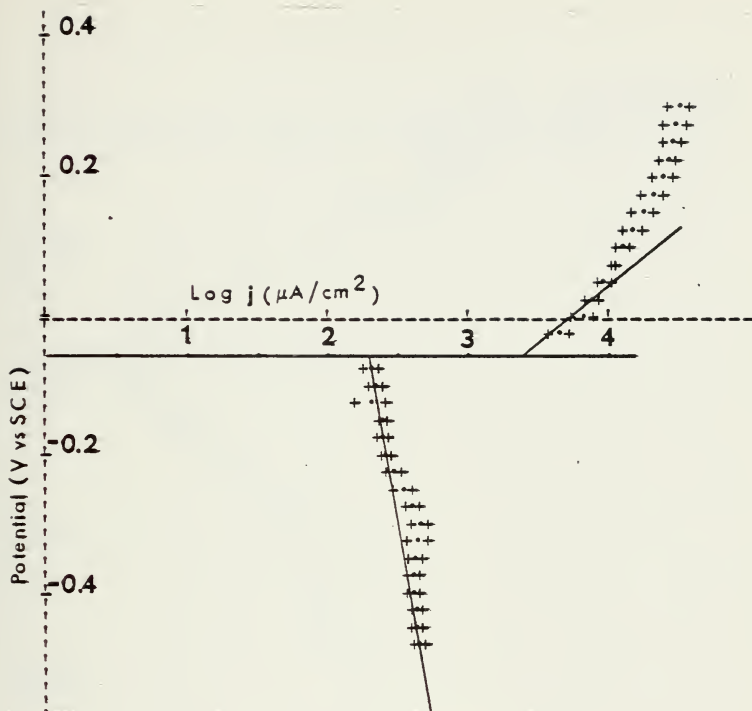


Figure 14. Copper in seawater treated with 89.65 ppm  $\text{OCl}^-$ .



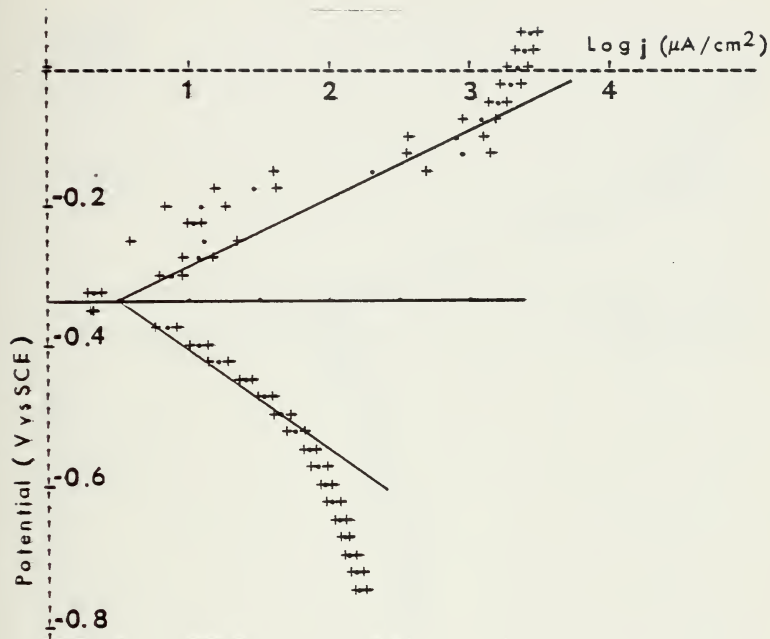


Figure 15. Nickel in untreated seawater.



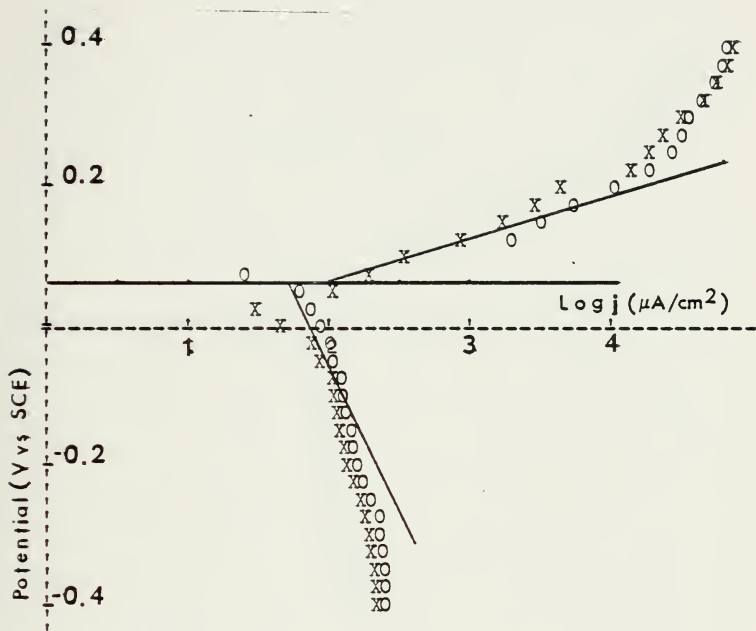


Figure 16. Nickel in seawater treated with 26.24 ppm  $\text{OCl}^-$ .



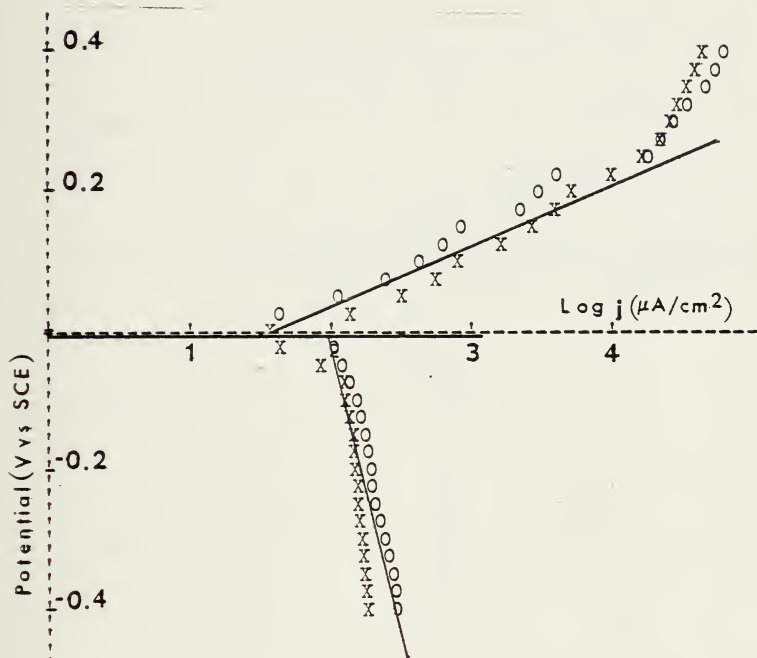


Figure 17. Nickel in seawater treated with 53.77 ppm  $\text{OCl}^-$ .





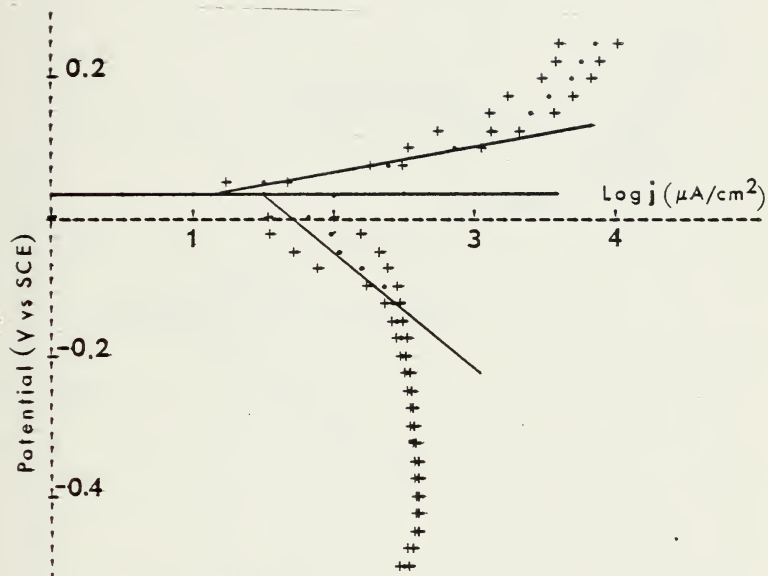


Figure 18. Nickel in seawater treated with 108.46 ppm  $\text{OCl}^-$ .



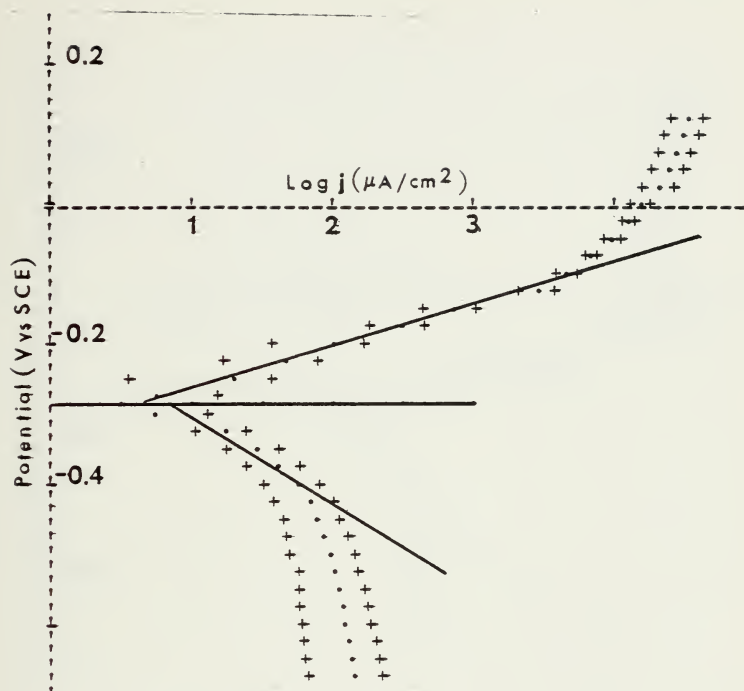


Figure 19. Naval brass in untreated seawater.



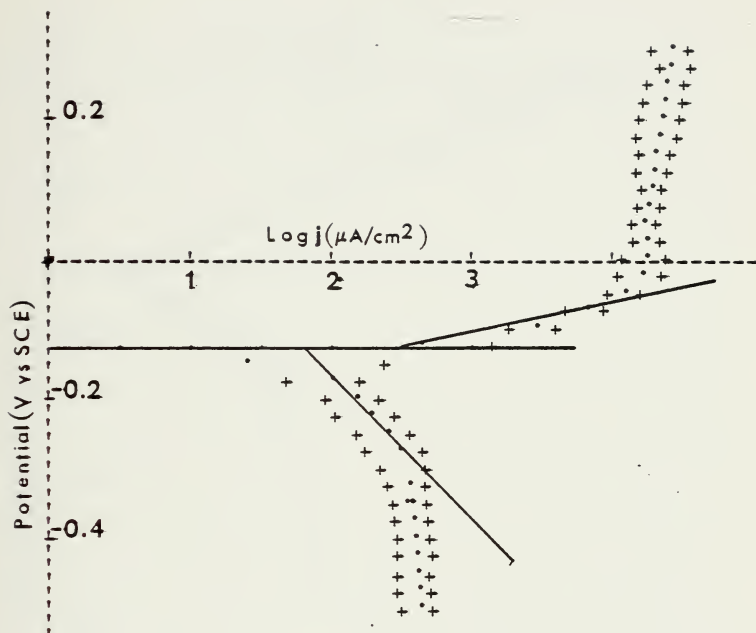


Figure 20. Naval brass in seawater treated with 93.29 ppm  $\text{OCl}^-$ .



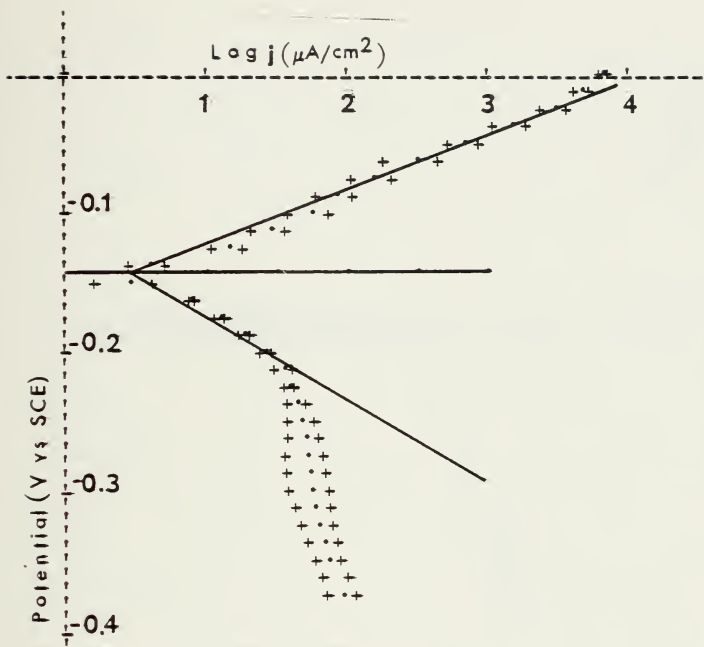


Figure 21. Copper-nickel (70/30) alloy  
in untreated seawater.





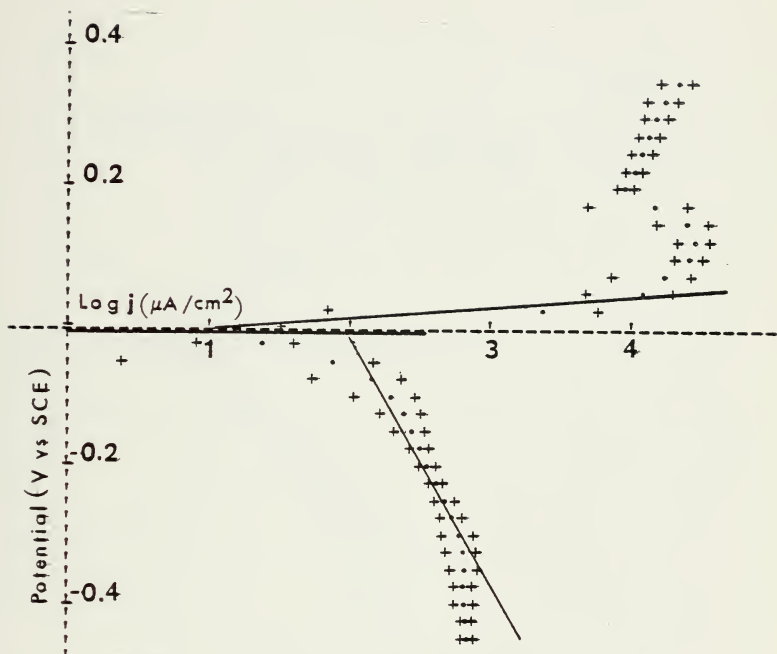


Figure 22. Copper-nickel (70/30) alloy  
in seawater treated with 102.22 ppm  $\text{OCl}^-$ .



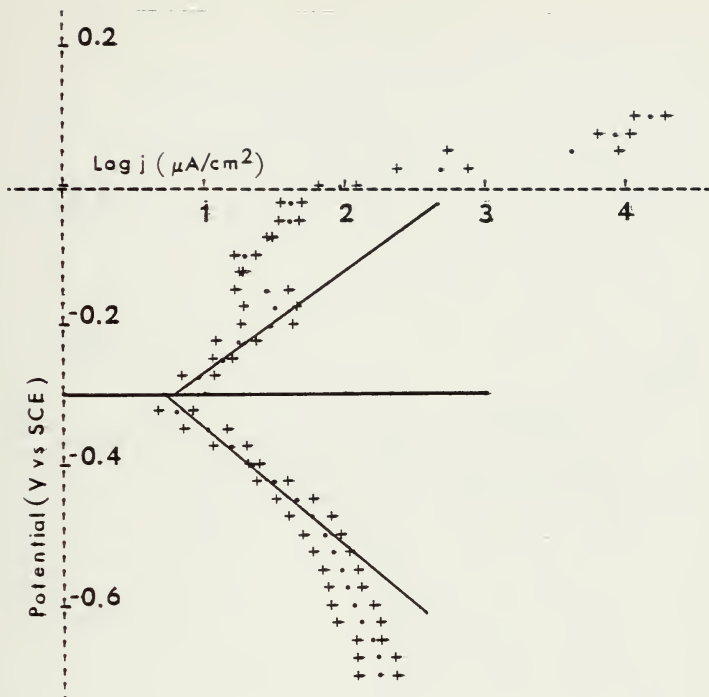


Figure 23. K-Monel in untreated seawater.



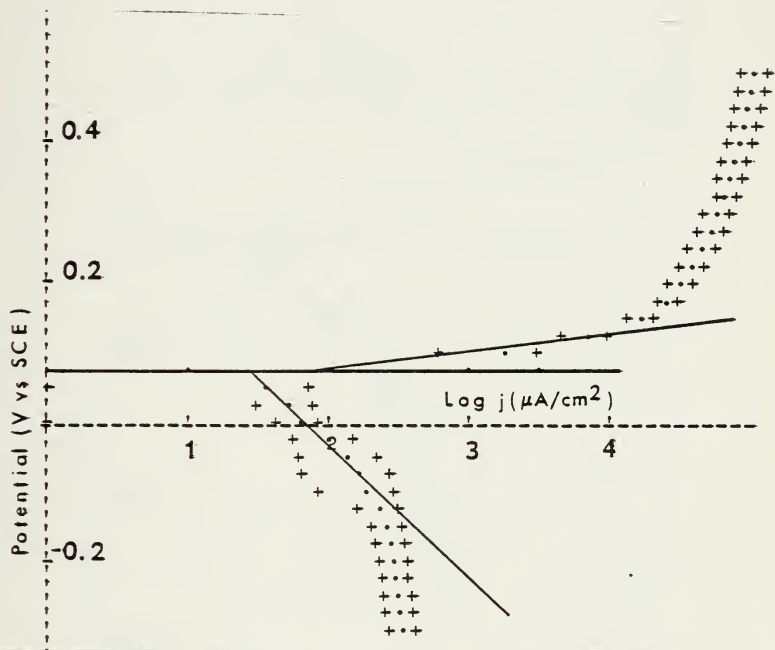


Figure 24. K-Monel in seawater treated  
with 88.85 ppm  $\text{OCl}^-$



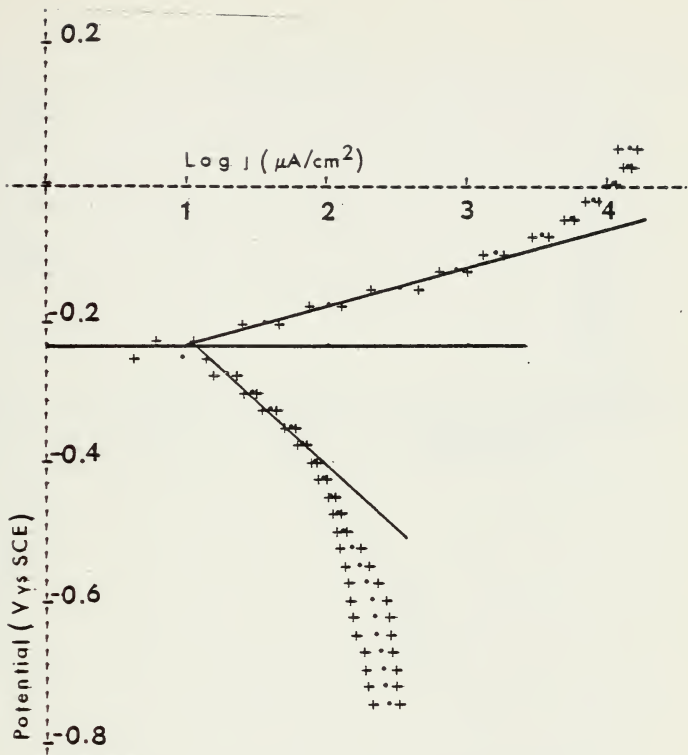


Figure 25. Phosphor bronze in untreated seawater.





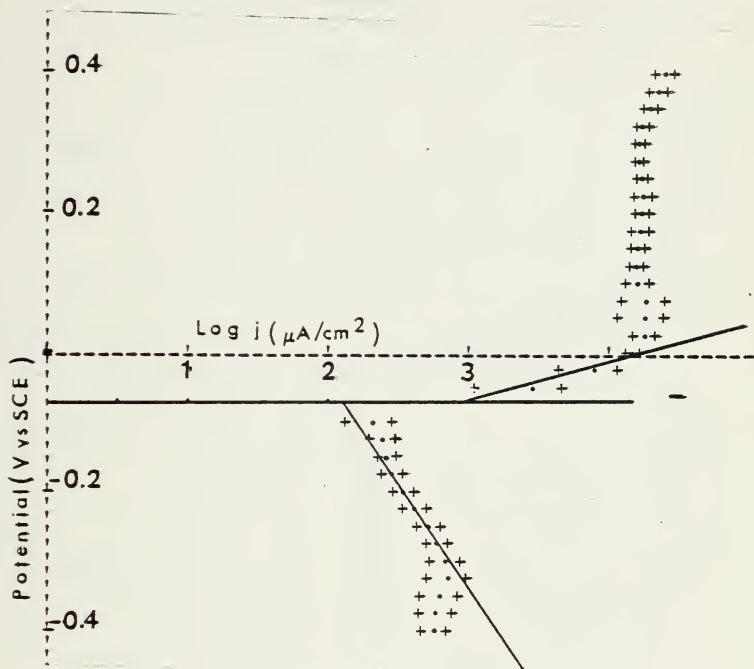
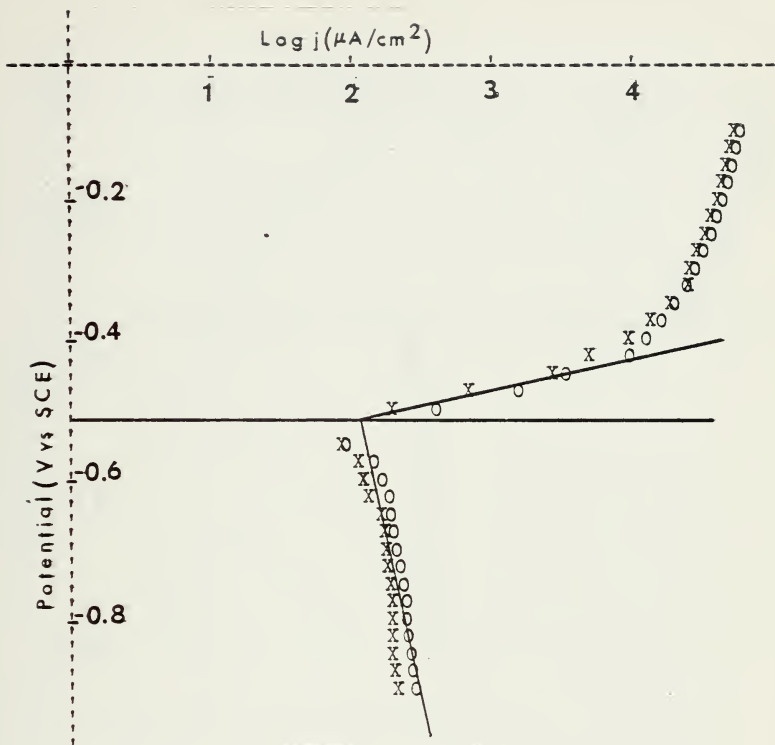


Figure 26. Phosphor bronze in seawater treated with 108.64 ppm  $\text{OCl}^-$ .







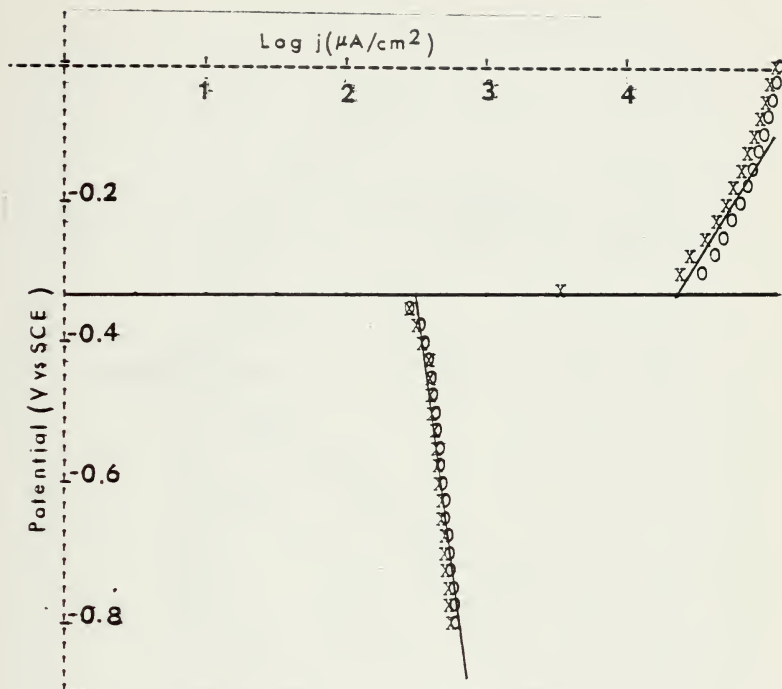


Figure 28. HY-80 steel alloy in seawater treated with 108.9 ppm  $\text{OCl}^-$ .



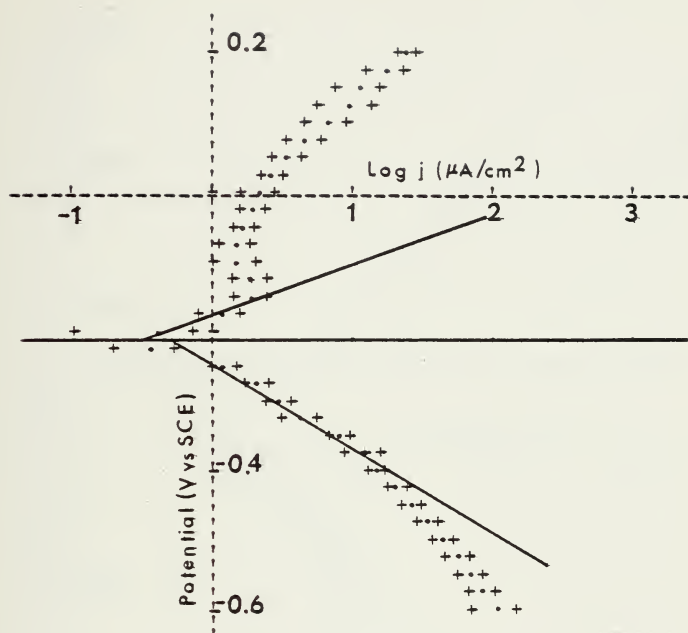


Figure 29. Stainless steel in untreated seawater.





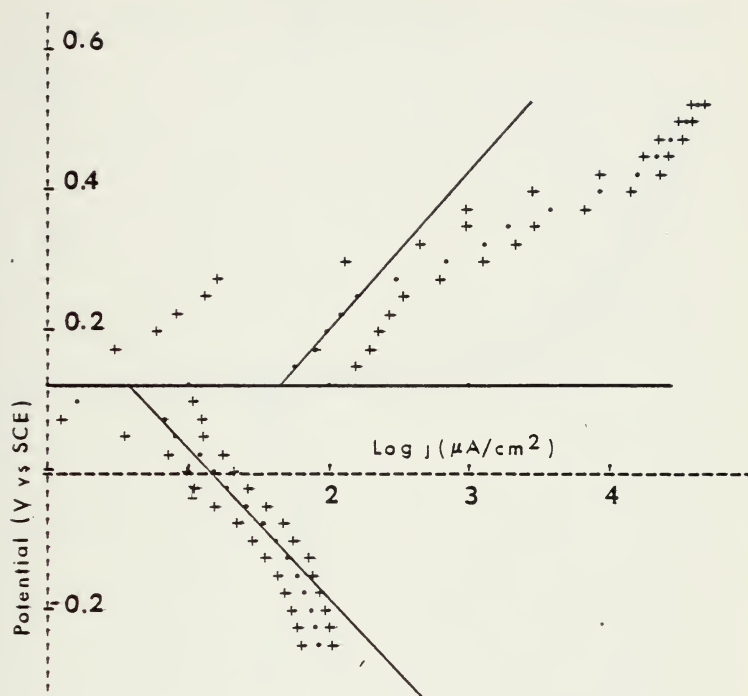


Figure 30. Stainless steel in seawater treated with 99.31 ppm  $\text{OCl}^-$ .



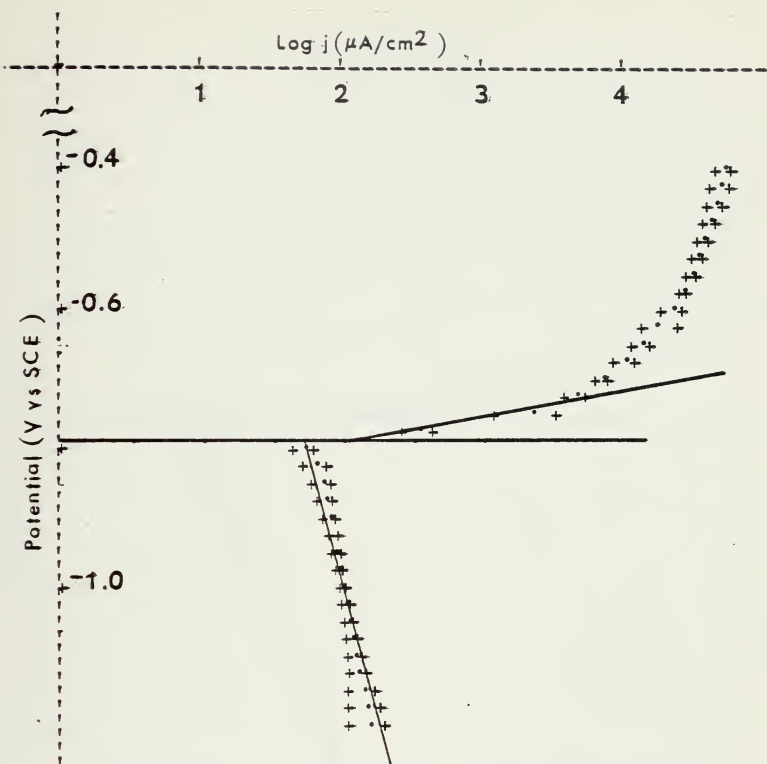


Figure 31. Aluminum alloy 7075 in untreated seawater.



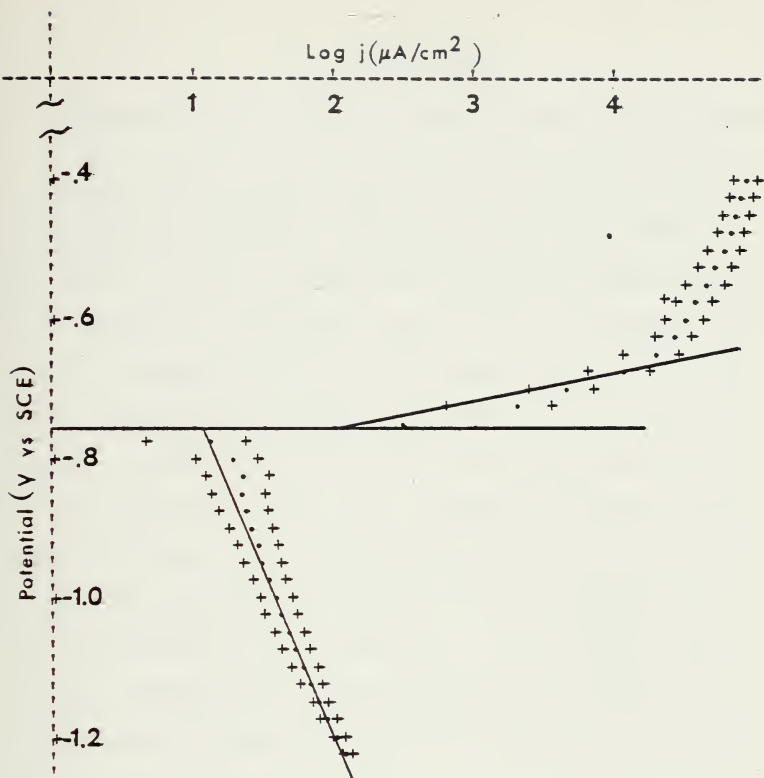


Figure 32. Aluminum alloy 7075 in seawater treated with 96.82 ppm  $\text{OCl}^-$ .



#### IV. CONCLUSIONS

##### A. DETERMINATION OF CORROSION RATES IN ARTIFICIAL SEAWATER

It has been reported that the instantaneous corrosion rates produced by potentiokinetic methods may differ by as much as two orders of magnitude from the average corrosion rates obtained by immersion tests [20]. The results obtained from this research, on the other hand, agreed quite well with those obtained by the immersion tests. Only in the cases of phosphor bronze, HY-80 steel and aluminum alloy 7075 did the measured corrosion rates fall outside the range of previously reported values, and even for the latter, the measured corrosion rates were of the correct order of magnitude. This close correlation corroborated that the cathodic overvoltage-intercept method could produce reasonable results, and that the artificial seawater-sodium thiosulfate system closely approximated natural seawater.

##### B. CORROSIVITY OF THE HYPOCHLORITE ION IN ARTIFICIAL SEAWATER

The addition of 100 ppm hypochlorite ion to artificial seawater increased the corrosion rate by two orders of magnitude for the copper and copper-nickel (70/30) alloy samples. The corrosion rates of nickel, naval brass, phosphor bronze, K-Monel, HY-80 steel and stainless steel were increased by a single order of magnitude. The corrosion rate of aluminum alloy 7075 decreased in the hypochlorite-seawater system.





The results obtained show some similarity to the qualitative values of corrosion resistance which Rabald has reported [21] for more concentrated sodium hypochlorite solutions. Rabald's remarks and comments, based on current research, are given in Table VI. Rabald uses the following symbology in the Table to describe the usefulness of the individual materials under ordinary conditions of pressure and temperature:

- + resistant
- (+) fairly resistant
- (-) not particularly resistant
- unusable.

These symbols can also be considered as upper limits of acceptable corrosion rates as given in Table V.

---

TABLE V

DEFINITION OF RABALD'S SYMBOLS

Symbol	Maximum corrosion rates (mm/year)			
	Al	Fe	Cu	Ni
+	0.11	0.11	.008	0.10
(+)	1.08	1.12	0.98	1.00
(-)	3.24	3.37	2.95	2.99

---

Rabald also provides a classification system for materials based upon general cost considerations and corrosion resistance. Using his guidelines, Table VII was constructed from the corrosion rates of the present work.



TABLE VI

CORROSION RESISTANCE OF METALS IN  
SODIUM HYPOCHLORITE SOLUTIONS

Aluminum alloys (without copper)

+ to -                      Room temp., solution up to 3% (20740 ppm)

Comment - Aluminum alloy 7075 experimentally shows increased resistance to corrosion in the 100 ppm  $\text{OCl}^-$  - seawater solution. It could be rated (+) using this criterion.

Bronze

(+) to (-)                  Room temp., solutions with 3% (20740 ppm) active chlorine.

Comment - The corrosion rate for phosphor bronze falls within the definition by Rabald as not particularly resistant (-).

Copper, Brass (60-90% copper)

+                              Room temp., solution under 2% (13830 ppm).  
Copper ions catalytically increase the decomposition  $\text{NaOCl}$  solution.

Comment - The corrosion rates determined for copper and naval brass in 100 ppm  $\text{OCl}^-$ -seawater solution classify copper as (-) and naval brass as (+).

Copper-Nickel alloys

+                              Room temp., 2% (13830 ppm) solution.

Comment - The corrosion rate determined for copper-nickel (70/30) alloy in 100 ppm  $\text{OCl}^-$ -seawater solution classify copper-nickel as (-) to -.



TABLE VI (Cont)

Iron, Cast Iron, and Steel

- Room temp., 0.1% (691 ppm) solution. Iron ions catalytically increase the decomposition of NaOCl.

Comment - The corrosion rate for HY-80 steel is well within the unusable region.

Austenitic chromium-nickel steels (18-20% Cr, 8-11% Ni, Stabilized)

- (+) to (-) Room temp., 5% (34570 ppm) solutions.  
Corrosion less than 1.1 mm/year. Severe pitting.

Comment - Stainless steel is resistant to corrosion in 100 ppm OCl<sup>-</sup>-seawater solution.

Nickel

- + to - Room temp., .1 g/l (69.1 ppm) solution. Penetration 0.10 mm/year.

Comment - Corrosion rate determined for nickel in 53.77 ppm OCl<sup>-</sup>-seawater solution was 1.01 mm/year. This classifies nickel as (-).

Monel metal

- + to - Room temp., 0.1 g/l (69.1 ppm) solution.  
Penetration 0.01 mm/year.

Comment - The corrosion rate determined for Monel in 100 ppm OCl<sup>-</sup>-seawater solution is .300 mm/year, which classifies Monel at (+).



TABLE VII

SUITABILITY OF METALS FOR USE IN  
HYPOCHLORITE-SEAWATER SYSTEMS

<u>Metal</u>	<u>Observed [OCl<sup>-</sup>] ppm</u>	<u>Economic Performance Rating</u>
Copper	0	Satisfactory
	34+	Do not use
Nickel	0	Satisfactory
	26+	Do not use
Naval brass	0	Satisfactory
	93.29	Use only under special conditions for short exposure
Phosphor bronze	0	Use with caution
	108.5	Do not use
Copper-nickel	0	Satisfactory
	102.2	Do not use
K-Monel	0	Satisfactory
	88.85	Use with caution
HY-80 steel	0	Use only under special conditions for short expo- sure
	104.5	Do not use
Stainless steel	0	Satisfactory
	99.31	Satisfactory
Aluminum 7075	0	Do not use
	96.82	Use with caution





#### C. CHANGE IN CORROSION POTENTIAL WITH HYPOCHLORITE ION CONCENTRATION

Another interesting phenomenon observed during the experimentation was the change in corrosion potential with the change in hypochlorite ion concentration. The exact relationship between the hypochlorite ion concentration and corrosion potential was not determined in this study.

#### D. SUMMARY

With the exception of the aluminum alloy, the effect of the addition of hypochlorite ion was the same for all materials evaluated, with the corrosion potential becoming more positive and the metal less resistant to corrosion. No attempt was made to extrapolate corrosion rates from higher hypochlorite ion concentrations to those lower concentrations at which the shipboard seawater systems are expected to operate, and the equipment precluded making accurate measurements at these lower (0.5 ppm) concentrations. However, if the changes in corrosion rate with hypochlorite ion concentration noted for copper and nickel are representative, then a noticeable increase in corrosion should occur in the seawater systems even with the 0.5 ppm concentration.



## V. RECOMMENDATIONS

Current literature contains little information about potentiokinetic studies of corrosion in seawater systems. The determination of the general resistance to corrosion, the types of corrosion, and the corrosion products developed in a marine environment are of great interest. Further research in this area, therefore, could be conducted using the present equipment with minimal expense, but with a great deal of patience and imagination to improve the equipment's performance and to extend the procedures. Among the changes recommended are:

- (1) The overhaul or replacement of the potentiostat.
  - (2) The procurement of a linear scan device to drive the potentiostat through the desired range at the desired rate.
  - (3) The procurement or modification of a logarithmic amplifier to facilitate the recording of data directly on a semi-logarithmic plot.
  - (4) The development and verification of a fast scan procedure, many of which are discussed in current literature.
- The subjects recommended for investigation are:
- (1) Verification of the result of this research.
  - (2) Determination of corrosion rates and potentials at lower hypochlorite ion concentrations.
  - (3) Extension of this research to other materials



with marine significance.

(4) Determination of type products and rate of corrosion with the additional use of the scanning electron microscope.

There are many other procedures advanced in the literature based on optical methods which allow measurements of the corrosion process without the introduction of an externally applied current. These methods could also be evaluated using equipment already on hand at the school.

A better understanding of the corrosion resistance of construction materials is necessary for the more efficient allocation of resources within the navy and civilian community. The school has the capability to make a contribution in this area with existing resources.



## APPENDIX A

### PREPARATION OF ARTIFICIAL SEAWATER

The formula and procedure developed by Kester, et al, were used in producing the quantity of synthetic standard seawater required. The seawater was manufactured in 36 kg amounts. This amount of water was normally consumed in ten working days.

The formula for 1 kg of artificial seawater given in Table VIII is designed to bring the composition of the artificial seawater to within 1 mg/kg of the major components in natural seawater. The impurities in reagent grade salts will not change the composition of artificial seawater by more than 1 mg/kg, but may cause great deviation from the composition with respect to the minor constituents. A comparison of the composition of standard natural seawater and artificial seawater is given in Table IX.

The solutions of the volumetric salts were initially prepared at 2.5 times greater concentration using new chemical stock, were diluted to the desired concentration and densities were checked prior to mixing in the final solution.

To avoid precipitation of insoluble compounds, the gravimetric salts were weighed and added to distilled water equivalent to 40% of the mass of the complete solution, the system was stirred and more distilled water was added to bring the total mass to 70% of the mass of the complete





solution. The volumetric salts were mixed in a separate container and distilled water added to bring the total mass to 30% of the complete solution. The two resulting solutions were added together and stirred overnight.

The pH and conductivity were measured and checked with standard seawater procured from I.A.S.P.O. Standard Seawater Service, Charlottenlund Slot, DK-2920, Charlottenlund, Denmark. The results of the comparisons are shown in Table X.



TABLE VIII

FORMULA FOR 1 kg OF ARTIFICIAL SEAWATERA. Gravimetric Salts

<u>Salt</u>	<u>g/kg of solution</u>
NaCl	23.926
Na <sub>2</sub> SO <sub>4</sub> (anhydrous)	4.008
KCl	0.677
NaHCO <sub>3</sub>	0.196
KBr	0.098
H <sub>3</sub> BO <sub>3</sub>	0.026
NaF	0.003

B. Volumetric Salts

<u>Salt</u>	<u>Conc M/l</u>	<u>ml/kg of solution</u>
MgCl <sub>2</sub> ·6H <sub>2</sub> O	1.000	53.27
CaCl <sub>2</sub> ·2H <sub>2</sub> O	1.000	10.33
SrCl <sub>2</sub> ·6H <sub>2</sub> O	0.100	0.90

C. Distilled water to bring total weight to 1 kg

The resulting pH should be between 7.9 and 8.3



TABLE IX

COMPARISON OF THE COMPOSITION OF  
NATURAL AND ARTIFICIAL SEAWATERS

Ion	Natural seawater (g/kg)	Artificial seawater (g/kg)	Difference %
Cl <sup>-</sup>	19.353	19.353	0.0
Na <sup>+</sup>	10.760	10.765	0.046
SO <sub>4</sub> <sup>--</sup>	2.712	2.711	0.037
Mg <sup>++</sup>	1.294	1.295	0.077
Ca <sup>++</sup>	0.413	0.414	0.24
K <sup>+</sup>	0.387	0.387	0.0
HCO <sub>3</sub> <sup>-</sup>	0.142	0.142	0.0
Br <sup>-</sup>	0.067	0.066	1.5
Sr <sup>++</sup>	0.008	0.008	0.0
H <sub>3</sub> BO <sub>3</sub>	0.026	0.026	0.0
F <sup>-</sup>	0.001	0.001	0.0



TABLE X

COMPARISON OF pH AND CONDUCTIVITY  
OF STANDARD AND ARTIFICIAL SEAWATERS

Date	Temp °C	Standard Seawater		Artificial Seawater	
		pH	Cond (mmho/cm)	pH	Cond (mmho/cm)
1/13/76	23	8.3	39.93	8.3	39.93
2/25/76	20	8.3	40.02	8.3	39.67
3/11/76	19	8.2	39.57	8.15	40.76
3/30/76	19.8	8.3	40.21	8.1	39.29
4/20/76	24	8.32	39.57	8.28	40.85





## APPENDIX B

### COMPOSITION OF METALLIC SAMPLES

With the exception of the pure metals, the samples used to manufacture the electrodes were provided by the Metallurgy Laboratory, Mare Island Naval Shipyard (MINSY), Vallejo, California, with the chemical assay reports. The pure metals were provided by the Department of Mechanical Engineering, Naval Postgraduate School, and were considered to be 99.99% pure.

The density of each specimen was determined in the laboratory. The gram-equivalent weight ( $e$ ) for the alloys was determined from the following formula:

$$e = \sum_{i=1}^n \frac{X_i A_i}{Z_i}$$

where:

$X_i$  is the mass fraction of the metal component

$A_i$  is the gram molecular weight of the metal component

$Z_i$  is the oxidation state of the predominant form  
of the naturally occurring oxides of the metal  
component.

A summary of the above properties for each sample is given in Table XI.



TABLE XI

## CHEMICAL COMPOSITION, EQUIVALENT WEIGHT AND DENSITY OF METAL SAMPLES

Alloy	Percent Composition	equivalent wt	$\frac{\rho}{\text{cm}^3}$
Copper	Cu(99.99)	31.77	8.933
Nickel	Ni(99.99)	29.355	8.86
Naval Brass QQ-B-750	Cu(61.3), Zn(38.10), Sn(.60), Fe(.10), Pb(.10), Other(.10).	32.418	8.319
Phosphor Bronze QQ-B-750	Cu(94.8), Sn(5.16), P(.04), Fe(<.05), Mn(<.05), Zn(<.05), Pb(<.02)	33.187	8.909
Copper Nickel M11-C-15726E	Cu(67.49), Ni(31.5), Fe(.58), Mn(.42), P(.007), Pb(<.05), Zn(<.05)	30.805	8.731
K-Monel Alloy K-500	Ni(65.30), Cu(29.50), Al(2.80), Fe(1.00), C(.15), Si(.15), Mn(.60), Ti(.50)	28.654	8.410
Steel HY-80	Fe(95.27), Ni(2.75), Cr(1.40), Mo(.40), C(.18)	27.734	7.857
Stainless Steel 304	Fe(71.59), Cr(18.36), Ni(9.06), Mn(.94), C(.05)	25.990	7.775
Aluminum Alloy 7075	Al(89.8), Mg(2.5), Cu(1.6), Cr(0.5), Zn(5.6)	10.805	2.749



## APPENDIX C

### TABLES OF EXPERIMENTAL DATA

The form in which experimental data were collected (Figure 9) was not suitable for inclusion within this paper. The tables which are included in this Appendix will allow the polarization curves of Figures 11 through 32 to be reproduced and the resulting values for the corrosion current density to be verified.

With the exception of the trials involving:

Steel alloy Hy-80, both trials;

Copper in seawater treated with 2.123 ml and  
4.245 ml CLOROX;

Nickel in seawater treated with 2.123 ml and  
4.245 ml CLOROX;

all data represent the summary of a minimum of four runs.

With the exception of the six enumerated trials, the data are presented as the mean and standard deviation (std. dev.). The six enumerated trials were duplicate runs only, and the data for each run are presented.

The values recorded for Potential and  $E_{\text{corr}}$  are valid to three significant digits, the values recorded for Current Density and  $\text{OCl}^-$  are valid to four significant digits. The data were prepared for presentation by a WANG 720C Computer.



TABLE XII

COPPER IN UNTREATED SEAWATER

Potential (V vs SCE)	Current Density ( $\mu\text{A}/\text{cm}^2$ )	
	Mean	Std. Dev.
.000	11750.000	770.000
-.025	8082.000	1381.000
-.050	4761.000	1044.000
-.075	2509.000	569.000
-.100	1125.000	222.000
-.125	476.800	70.700
-.150	162.000	37.300
-.175	78.070	12.850
-.200	39.080	6.740
-.225	20.640	1.800
-.250	7.223	1.670
-.275	-4.640	2.080
-.300	-12.760	3.730
-.325	-19.650	4.450
-.350	-29.370	3.440
-.375	-40.220	2.960
-.400	-51.500	2.980
-.425	-61.680	4.890
-.450	-71.870	8.290
-.475	-78.170	7.960
-.500	-85.970	8.130
-.525	-92.080	9.550
-.550	-97.160	13.550
-.575	-100.600	11.100
-.600	-103.500	12.200
-.625	-108.000	12.300
-.650	-111.100	12.800
-.675	-114.000	14.300
-.700	-116.600	14.900
-.725	-119.200	16.300
-.750	-121.500	16.800
-.775	-127.400	21.100
-.800	-130.400	20.700
Mean		Std. Dev.
$E_{\text{corr}}$ (V vs SCE)	-.266	.016





TABLE XIII

COPPER IN SEAWATER TREATED WITH 2.123 ml CLOROX

Potential (V vs SCE)	Current Density ( $\mu\text{A}/\text{cm}^2$ )	
	Run 1	Run 2
.250	44590.000	34440.000
.225	38710.000	30660.000
.200	34660.000	26660.000
.175	30200.000	22220.000
.150	24120.000	17770.000
.125	20270.000	13550.000
.100	15810.000	11110.000
.075	14190.000	9331.000
.050	13180.000	8331.000
.025	14590.000	7776.000
.000	16220.000	7554.000
-.025	17840.000	7332.000
-.050	12770.000	6665.000
-.075	8939.000	4110.000
-.100	5655.000	2444.000
-.125	3142.000	888.700
-.150	1095.000	64.430
-.175	57.770	-38.370
-.200	-36.280	-101.000
-.225	-109.500	-133.300
-.250	-170.300	-165.600
-.275	-291.900	-193.900
-.300	-352.700	-202.000
-.325	-385.100	-240.300
-.350	-385.100	-264.600
-.375	-397.300	-292.900
-.400	-425.700	-333.300
-.425	-441.900	-345.400
-.450	-464.200	-365.600
-.475	-468.200	-401.900
-.500	-506.700	-403.900
-.525	-547.300	-414.000
-.550	-567.500	-426.200
-.575	-589.800	-442.300
-.600	-644.600	-446.400
-.625	-687.100	-464.500

	<u>Run 1</u>	<u>Run 2</u>
$E_{\text{corr}}$ (V vs SCE)	-.182	-.166

[ $\text{OCl}^-$ ] ppm      32.400                      34.970



## TABLE XIV

COPPER IN SEAWATER TREATED WITH 4.25 ml CLOROX

Potential (V vs SCE)	Current Density ( $\mu\text{A}/\text{cm}^2$ )	
	<u>Run 1</u>	<u>Run 2</u>
.400	79540.000	74190.000
.375	68960.000	69160.000
.350	65300.000	65540.000
.325	60620.000	60120.000
.300	55330.000	56500.000
.275	52480.000	52480.000
.250	48420.000	48250.000
.225	43740.000	45240.000
.200	38450.000	40010.000
.175	32340.000	33780.000
.150	27670.000	27950.000
.125	22170.000	23930.000
.100	18510.000	19900.000
.075	16070.000	15880.000
.050	13830.000	13070.000
.025	12000.000	11860.000
.000	9968.000	9852.000
-.025	11190.000	10660.000
-.050	7730.000	7841.000
-.075	3662.000	4343.000
-.100	-388.500	1970.000
-.125	-469.900	-120.600
-.150	-510.600	-402.100
-.175	-463.800	-418.900
-.200	-463.800	-420.200
-.225	-510.600	-438.300
-.250	-553.300	-478.500
-.275	-592.000	-502.600
-.300	-579.300	-512.700
-.325	-559.400	-512.700
-.350	-565.500	-532.800
-.375	-575.700	-554.900
-.400	-608.200	-565.000
-.425	-626.600	-587.100
-.450	-636.700	-605.200
-.475	-651.000	-623.300
-.500	-669.300	-641.400

	<u>Run 1</u>	<u>Run 2</u>
$E_{\text{corr}}$ (V vs SCE)	-.086	-.116

[OCl<sup>-</sup>] ppm 55.080                      57.670



TABLE XV

COPPER IN SEAWATER TREATED WITH 8.49 ml CLOROX

<u>Potential</u> (V vs SCE)	<u>Current Density (<math>\mu\text{A}/\text{cm}^2</math>)</u>	
	<u>Mean</u>	<u>Std. Dev.</u>
.400	44600.000	10520.000
.375	41010.000	9670.000
.350	37820.000	8190.000
.325	34950.000	7170.000
.300	32570.000	6210.000
.275	30710.000	5600.000
.250	29480.000	4400.000
.225	27140.000	3720.000
.200	24910.000	4170.000
.175	21030.000	3810.000
.150	17840.000	3320.000
.125	15110.000	2500.000
.100	12870.000	1468.000
.075	11250.000	540.000
.050	9231.000	735.000
.025	7725.000	853.000
.000	6705.000	1236.000
-.025	4545.000	772.000
-.050	-20.170	34.960
-.075	-205.700	24.100
-.100	-222.500	24.300
-.125	-208.200	50.500
-.150	-247.800	17.400
-.175	-250.300	22.000
-.200	-262.900	20.600
-.225	-299.300	39.200
-.250	-347.000	53.100
-.275	-401.500	45.400
-.300	-458.600	61.200
-.325	-442.400	79.200
-.350	-424.400	46.600
-.375	-408.500	43.700
-.400	-412.800	42.400
-.425	-431.300	37.000
-.450	-434.900	39.800
-.475	-453.400	39.400
-.500	-455.200	61.100

	<u>Mean</u>	<u>Std. Dev.</u>
$E_{\text{corr}}$ (V vs SCE)	-.059	.012

[OCl<sup>-</sup>] ppm 89.650 7.240



TABLE XVI

NICKEL IN UNTREATED SEAWATER

Potential (V vs SCE)	Current Density ( $\mu\text{A}/\text{cm}^2$ )	
	<u>Mean</u>	<u>Std. Dev.</u>
.100	3266.000	459.000
.075	2996.000	433.000
.050	2769.000	391.000
.025	2536.000	364.000
.000	2255.000	381.000
-.025	2022.000	357.000
-.050	1632.000	241.000
-.075	1240.000	340.000
-.100	821.500	455.100
-.125	897.900	540.100
-.150	207.400	283.500
-.175	28.930	13.620
-.200	12.580	5.700
-.225	11.160	1.380
-.250	13.000	9.150
-.275	11.980	2.980
-.300	7.689	1.390
-.325	2.182	.246
-.350	-2.076	.055
-.375	-7.085	1.224
-.400	-11.850	1.760
-.425	-16.320	2.730
-.450	-25.330	2.540
-.475	-34.430	4.380
-.500	-45.450	6.180
-.525	-56.960	3.150
-.550	-70.970	7.410
-.575	-82.940	10.730
-.600	-92.860	8.650
-.625	-104.400	11.500
-.650	-116.700	10.300
-.675	-125.900	8.930
-.700	-136.800	11.600
-.725	-152.000	15.200
-.750	160.600	13.500
	<u>Mean</u>	<u>Std. Dev.</u>
$E_{\text{corr}}$ (V vs SCE)	-.338	.000





TABLE XVII

NICKEL IN SEAWATER TREATED WITH 2.123 ml CLOROX

Potential (V vs SCE)	Current Density ( $\mu\text{A}/\text{cm}^2$ )	
	Run 1	Run 2
.400	68380.000	75070.000
.375	63690.000	68440.000
.350	55600.000	56890.000
.325	44950.000	45990.000
.300	36430.000	32300.000
.275	32590.000	23740.000
.250	27910.000	19040.000
.225	19380.000	13900.000
.200	10890.000	4385.000
.175	5517.000	2887.000
.150	3238.000	1732.000
.125	2024.000	855.500
.100	.000	346.500
.075	-25.560	192.500
.050	-61.780	104.800
.025	-74.560	29.940
.000	-87.340	-44.920
-.025	-104.400	-74.860
-.050	-108.600	-85.560
-.075	-123.600	-104.800
-.100	-127.800	-109.100
-.125	-132.100	-113.400
-.150	-147.000	-117.600
-.175	-151.200	-128.300
-.200	-161.900	-134.700
-.225	-174.700	-149.700
-.250	-202.400	-169.000
-.275	-234.300	-181.800
-.300	-234.300	-194.600
-.325	-242.800	-196.800
-.350	-255.600	-211.700
-.375	-255.600	-213.900
-.400	-255.600	-218.200

	<u>Run 1</u>	<u>Run 2</u>
$E_{\text{corr}}$ (V vs SCE)	.101	.023

[ $\text{OCl}^-$ ] ppm    28.510                      23.970



TABLE XVIII

NICKEL IN SEAWATER TREATED WITH 4.245 ml CLOROX

Potential (V vs SCE)	Current Density ( $\mu\text{A}/\text{cm}^2$ )	
	<u>Run 1</u>	<u>Run 2</u>
.400	63740.000	44200.000
.375	55720.000	39060.000
.350	47290.000	34540.000
.325	34950.000	29200.000
.300	27760.000	26110.000
.275	22820.000	22210.000
.250	18300.000	16450.000
.225	4112.000	9869.000
.200	3063.000	5161.000
.175	2262.000	3927.000
.150	865.600	2693.000
.125	637.400	1645.000
.100	431.800	801.800
.075	246.700	555.100
.050	113.100	318.700
.025	43.180	135.700
.000	.000	37.000
-.025	-104.900	-43.180
-.050	-121.300	-84.300
-.075	-135.700	-123.400
-.100	-154.200	-125.400
-.125	-164.500	-133.600
-.150	-174.800	-141.900
-.175	-185.000	-143.900
-.200	-193.300	-146.000
-.225	-199.400	-152.100
-.250	-207.700	-154.200
-.275	-224.100	-158.300
-.300	-244.700	-162.400
-.325	-261.100	-166.500
-.350	-275.500	-170.600
-.375	-289.900	-174.800
-.400	-294.000	-178.900

	<u>Run 1</u>	<u>Run 2</u>
$E_{\text{corr}}$ (V vs SCE)	-.005	-.012

[OC1 <sup>-</sup> ] ppm	57.020	50.540
-------------------------	--------	--------



TABLE XIX

NICKEL IN SEAWATER TREATED WITH 8.49 ml CLOROX

Potential (V vs SCE)	Current Density ( $\mu\text{A}/\text{cm}^2$ )	
	<u>Mean</u>	<u>Std. Dev.</u>
.250	7291.000	3687.000
.225	5869.000	2049.000
.200	4991.000	1917.000
.175	3427.000	1677.000
.150	2531.000	1215.000
.125	1342.000	786.000
.100	738.000	396.000
.075	247.600	62.900
.050	32.180	14.880
.025	-13.760	26.130
.000	-67.300	33.130
-.025	-96.440	61.420
-.050	-111.900	59.700
-.075	-159.600	83.100
-.100	-230.000	56.800
-.125	-266.200	33.100
-.150	-285.700	26.900
-.175	-305.800	26.100
-.200	-312.700	12.900
-.225	-332.800	16.200
-.250	-348.900	13.200
-.275	-357.800	8.300
-.300	-364.300	12.500
-.325	-374.700	11.600
-.350	-389.000	16.400
-.375	-392.200	13.200
-.400	-393.800	11.200
-.425	-390.800	7.700
-.450	-388.400	11.500
-.475	-351.700	15.200
-.500	-317.700	26.300
	<u>Mean</u>	<u>Std. Dev.</u>
$E_{\text{corr}}$ (V vs SCE)	.033	.012
[OC1 <sup>-</sup> ] ppm	108.500	3.370



TABLE XX

NAVAL BRASS IN UNTREATED SEAWATER

Potential (V vs SCE)	Current Density ( $\mu\text{A}/\text{cm}^2$ )	
	Mean	Std. Dev.
.125	35150.000	8930.000
.100	32180.000	8780.000
.075	28460.000	7250.000
.050	25560.000	6510.000
.025	21710.000	5650.000
.000	15890.000	2420.000
-.025	12970.000	1330.000
-.050	9936.000	1409.000
-.075	7042.000	620.000
-.100	4747.000	802.000
-.125	2988.000	898.000
-.150	750.300	308.500
-.175	320.700	134.900
-.200	102.600	65.800
-.225	47.740	30.930
-.250	20.230	16.640
-.275	5.628	9.606
-.300	-5.620	7.372
-.325	-17.530	6.820
-.350	-29.460	11.770
-.375	-41.320	17.030
-.400	-56.440	24.630
-.425	-69.590	31.930
-.450	-77.390	33.260
-.475	-86.970	40.560
-.500	-95.610	46.740
-.525	-103.800	47.400
-.550	-112.000	55.000
-.575	-117.600	60.100
-.600	-122.900	63.200
-.625	-130.900	70.300
-.650	-135.800	73.900
-.675	-142.200	76.800
	<u>Mean</u>	<u>Std. Dev.</u>
$E_{\text{corr}}$ (V vs SCE)	-.287	.012





TABLE XXI

NAVAL BRASS IN SEAWATER TREATED WITH 8.49 ml CLOROX

Potential (V vs SCE)	Current Density ( $\mu\text{A}/\text{cm}^2$ )	
	Mean	Std. Dev.
.300	27300.000	7810.000
.275	26400.000	7480.000
.250	25110.000	7320.000
.225	24420.000	7450.000
.200	22930.000	7320.000
.175	21980.000	6910.000
.150	20750.000	5130.000
.125	19970.000	4960.000
.100	19590.000	3090.000
.075	18580.000	3370.000
.050	17230.000	3360.000
.025	18100.000	3960.000
.000	18000.000	6070.000
-.025	16810.000	5670.000
-.050	12640.000	3220.000
-.075	6771.000	2039.000
-.100	2960.000	1084.000
-.125	449.800	970.000
-.150	25.230	217.000
-.175	-104.500	55.700
-.200	-157.100	65.100
-.225	-196.000	88.200
-.250	-259.300	107.900
-.275	-313.100	136.800
-.300	-347.500	121.300
-.325	-364.700	113.200
-.350	-381.700	106.100
-.375	-393.100	105.700
-.400	-401.500	105.400
-.425	-413.900	114.300
-.450	-420.700	108.600
-.475	-428.100	112.400
-.500	-442.400	110.300
	<u>Mean</u>	<u>Std. Dev.</u>
$E_{\text{corr}}$ (V vs SCE)	-.132	.023
$[\text{OCl}^-]$ ppm	93.290	1.130



TABLE XXII

PHOSPHOR BRONZE IN UNTREATED SEAWATER

Potential (V vs SCE)	Current Density ( $\mu\text{A}/\text{cm}^2$ )	
	<u>Mean</u>	<u>Std. Dev.</u>
.050	14470.000	2430.000
.025	14340.000	970.000
.000	11060.000	830.000
-.025	8057.000	891.000
-.050	5498.000	472.000
-.075	3430.000	469.000
-.100	1615.000	275.000
-.125	846.300	188.700
-.150	335.000	122.700
-.175	102.900	26.600
-.200	35.640	10.250
-.225	8.692	2.645
-.250	-9.141	4.949
-.275	-19.350	3.830
-.300	-29.040	3.180
-.325	-39.700	4.950
-.350	-56.040	5.260
-.375	-67.600	5.930
-.400	-82.520	4.350
-.425	-94.690	6.630
-.450	-109.100	6.700
-.475	-119.000	7.700
-.500	-129.700	10.200
-.525	-151.100	26.000
-.550	-168.300	32.800
-.575	-187.500	45.500
-.600	-205.700	60.600
-.625	-215.100	60.900
-.650	-223.000	63.100
-.675	-237.000	55.000
-.700	-248.300	62.000
-.725	-256.300	57.000
-.750	-269.700	58.200
	<u>Mean</u>	<u>Std. Dev.</u>
$E_{\text{corr}}$ (V vs SCE)	-.236	.004



TABLE XXIII

PHOSPHOR BRONZE IN SEAWATER TREATED WITH 9.49 ml CLOROX

Potential (V vs SCE)	Current Density ( $\mu\text{A}/\text{cm}^2$ ) Mean	Std. Dev.
.400	25750.000	4210.000
.375	23240.000	3430.000
.350	20370.000	2180.000
.325	17750.000	1850.000
.300	16900.000	1400.000
.275	16900.000	1220.000
.250	17700.000	1750.000
.225	18000.000	2630.000
.200	17750.000	2050.000
.175	17040.000	2510.000
.150	16440.000	1810.000
.125	16040.000	1790.000
.100	16540.000	3340.000
.075	18810.000	6500.000
.050	18400.000	6690.000
.025	18250.000	3210.000
.000	14930.000	1700.000
-.025	7994.000	3554.000
-.050	2885.000	1777.000
-.075	-74.800	184.600
-.100	-210.600	77.100
-.125	-248.000	50.900
-.150	-266.000	41.000
-.175	-293.600	52.500
-.200	-351.900	62.300
-.225	-426.400	82.300
-.250	-532.900	99.300
-.275	-611.900	102.600
-.300	-707.000	174.700
-.325	-737.200	234.200
-.350	-645.100	188.600
-.375	-599.300	161.300
-.400	-579.700	122.300
	Mean	Std. Dev.
$E_{\text{corr}}$ (V vs SCE)	-.071	.009
$[\text{OCl}^-]$ ppm	108.500	3.400



TABLE XXIV

COPPER-NICKEL ALLOY IN UNTREATED SEAWATER

<u>Potential</u> (V vs SCE)	<u>Current Density (<math>\mu\text{A}/\text{cm}^2</math>)</u>	
	<u>Mean</u>	<u>Std. Dev.</u>
.000	6893.000	511.000
-.025	4813.000	558.000
-.050	3107.000	666.000
-.075	1516.000	398.000
-.100	703.400	169.000
-.125	319.200	133.800
-.150	158.400	50.900
-.175	86.190	24.890
-.200	56.640	18.280
-.225	29.080	7.890
-.250	14.740	3.570
-.275	4.043	1.164
-.300	-2.939	1.312
-.325	-8.046	.296
-.350	-12.610	.910
-.375	-18.940	1.760
-.400	-26.650	2.570
-.425	-35.880	5.580
-.450	-39.330	3.120
-.475	-43.970	6.790
-.500	-47.790	10.070
-.525	-50.290	12.450
-.550	-51.510	15.810
-.575	-53.730	16.630
-.600	-55.180	17.730
-.625	-58.400	16.640
-.650	-62.080	15.720
-.675	-67.750	16.100
-.700	-73.490	15.040
-.725	-82.950	17.030
-.750	-92.020	21.890
	<u>Mean</u>	<u>Std. Dev.</u>
$E_{\text{corr}}$ (V vs SCE)	-.238	.000





TABLE XXV

COPPER-NICKEL ALLOY IN SEAWATER TREATED WITH 8.49 ml CLOROX

Potential (V vs SCE)	Current Density ( $\mu\text{A}/\text{cm}^2$ )	
	Mean	Std. Dev.
.350	21880.000	5430.000
.325	17420.000	4280.000
.300	15280.000	2920.000
.275	13620.000	2240.000
.250	12230.000	2150.000
.225	10720.000	1570.000
.200	9220.000	1260.000
.175	15040.000	10090.000
.150	25550.000	10150.000
.125	29300.000	7570.000
.100	26560.000	6130.000
.075	17390.000	10030.000
.050	12580.000	7720.000
.025	2440.000	3748.000
.000	16.660	16.340
-.025	-24.350	16.070
-.050	-76.010	73.570
-.075	-144.800	39.900
-.100	-203.700	94.700
-.125	-248.300	81.100
-.150	-283.200	70.600
-.175	-324.000	53.600
-.200	-371.200	51.800
-.225	-427.000	49.800
-.250	-497.300	83.100
-.275	-552.500	95.700
-.300	-621.800	158.900
-.325	-692.000	162.400
-.350	-689.300	156.000
-.375	-670.500	105.700
-.400	-678.100	108.100
-.425	-704.800	68.100
-.450	-713.200	73.200
	<u>Mean</u>	<u>Std. Dev.</u>
$E_{\text{corr}}$ (V vs SCE)	-.010	.008
$[\text{OCl}^-]$ ppm	102.200	9.030



TABLE XXVI

K-MONEL IN UNTREATED SEAWATER

Potential (V vs SCE)	Current Density ( $\mu\text{A}/\text{cm}^2$ )	
	Mean	Std. Dev.
.100	15440.000	3720.000
.075	8667.000	2265.000
.050	4172.000	4142.000
.025	500.200	260.600
.000	94.100	28.620
-.025	42.030	7.320
-.050	40.770	6.320
-.075	29.230	1.360
-.100	19.810	3.330
-.125	18.270	.680
-.150	28.090	11.590
-.175	32.240	13.250
-.200	29.990	12.060
-.225	17.490	5.490
-.250	13.570	2.110
-.275	9.218	2.341
-.300	-.258	.789
-.325	-6.375	1.770
-.350	-10.610	3.590
-.375	-15.550	4.110
-.400	-22.190	1.990
-.425	-30.990	7.590
-.450	-45.260	13.280
-.475	-58.460	19.200
-.500	-70.810	21.480
-.525	-81.700	23.130
-.550	-94.080	26.340
-.575	-102.500	28.300
-.600	-116.700	38.800
-.625	-131.600	46.200
-.650	-158.100	38.700
-.675	-172.800	51.800
-.700	-177.400	54.600
	<u>Mean</u>	<u>Std. Dev.</u>
$E_{\text{corr}}$ (V vs SCE)	-.300	.003



TABLE XXVII

K-MONEL IN SEAWATER TREATED WITH 8.49 ml CLOROX

Potential (V vs SCE)	Current Density ( $\mu\text{A}/\text{cm}^2$ )	
	Mean	Std. Dev.
.500	109600.000	23320.000
.475	104000.000	22710.000
.450	97630.000	20510.000
.425	91780.000	19000.000
.400	85320.000	17700.000
.375	78950.000	16030.000
.350	73380.000	14910.000
.325	66300.000	14120.000
.300	59580.000	12860.000
.275	53800.000	11640.000
.250	46230.000	10020.000
.225	39400.000	8030.000
.200	32720.000	6580.000
.175	26150.000	4250.000
.150	17010.000	3800.000
.125	7093.000	2530.000
.100	1836.000	1233.000
.075	27.870	113.600
.050	-36.140	36.140
.025	-53.670	23.440
.000	-63.710	21.350
-.025	-102.700	47.100
-.050	-140.500	79.000
-.075	-167.200	103.700
-.100	-187.000	102.800
-.125	-234.900	75.100
-.150	-267.000	65.500
-.175	-283.000	66.300
-.200	-298.500	68.900
-.225	-306.500	63.500
-.250	-318.500	71.400
-.275	-327.900	71.300
-.300	-344.000	73.200
	<u>Mean</u>	<u>Std. Dev.</u>
$E_{\text{corr}}$ (V vs SCE)	.077	.018
$[\text{OCl}^-]$ ppm	88.850	2.800



TABLE XXVIII

HY-80 STEEL ALLOY IN UNTREATED SEAWATER

Potential (V vs SCE)	Current Density ( $\mu\text{A}/\text{cm}^2$ )	
	Run 1	Run 2
.000	77060.000	63150.000
-.025	73800.000	62740.000
-.050	68920.000	58490.000
-.075	65060.000	55660.000
-.100	61000.000	53230.000
-.125	57540.000	49380.000
-.150	52860.000	46550.000
-.175	49000.000	42700.000
-.200	44930.000	40280.000
-.225	41270.000	36230.000
-.250	37610.000	32380.000
-.275	32730.000	28540.000
-.300	28260.000	25300.000
-.325	24600.000	24700.000
-.350	20330.000	18300.000
-.375	16270.000	13340.000
-.400	12710.000	9229.000
-.425	9556.000	4857.000
-.450	3456.000	2631.000
-.475	1566.000	665.900
-.500	404.600	190.200
-.525	-12.200	.000
-.550	-89.460	-82.980
-.575	-144.400	-109.300
-.600	-162.700	-117.400
-.625	-185.000	-127.500
-.650	-189.100	-157.900
-.675	-199.300	-163.900
-.700	-207.400	-166.000
-.725	-221.600	-172.000
-.750	-233.800	-180.100
-.775	-239.900	-182.200
-.800	-244.000	-182.200
-.825	-248.000	-182.200
-.850	-262.300	-182.200
-.875	-268.400	-192.300
-.900	-280.600	-202.400
	<u>Run 1</u>	<u>Run 2</u>
$E_{\text{corr}}$ (V vs SCE)	-.512	-.528





TABLE XXIX

HY-80 STEEL ALLOY IN SEAWATER TREATED WITH 8.49 ml CLOROX

Potential (V vs SCE)	Current Density ( $\mu\text{A}/\text{cm}^2$ )	
	Run 1	Run 2
.000	125500.000	114900.000
-.025	118400.000	107000.000
-.050	110600.000	99780.000
-.075	103100.000	90510.000
-.100	95950.000	82650.000
-.125	88190.000	73580.000
-.150	80640.000	67330.000
-.175	73490.000	58860.000
-.200	65530.000	52210.000
-.225	57360.000	43940.000
-.250	48990.000	36490.000
-.275	42670.000	28420.000
-.300	34700.000	24190.000
-.325	.000	3427.000
-.350	-285.800	-282.200
-.375	-338.900	-322.500
-.400	-367.500	-352.800
-.425	-398.100	-389.100
-.450	-408.300	-405.200
-.475	-418.500	-403.200
-.500	-438.900	-413.200
-.525	-449.100	-433.400
-.550	-469.500	-439.400
-.575	-469.500	-447.500
-.600	-500.100	-463.600
-.625	-520.600	-483.800
-.650	-520.600	-487.800
-.675	-541.000	-504.000
-.700	-561.400	-506.000
-.725	-571.600	-524.100
-.750	-602.200	-544.300
-.775	-612.400	-548.300
-.800	-612.400	-564.400

	<u>Run 1</u>	<u>Run 2</u>
$E_{\text{corr}}$ (V vs SCE)	-.325	-.344

$[\text{OCl}^-]$ ppm	100.100	108.900
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TABLE XXX

STAINLESS STEEL IN UNTREATED SEAWATER

Potential (V vs SCE)	Current Density ( $\mu\text{A}/\text{cm}^2$ )	
	Mean	Std. Dev.
.200	24.760	3.800
.175	17.800	5.340
.150	11.530	4.110
.125	9.552	3.975
.100	6.817	2.275
.075	4.645	1.283
.050	3.467	.831
.025	2.683	.491
.000	2.216	.602
-.025	1.962	.387
-.050	1.685	.295
-.075	1.482	.377
-.100	1.486	.531
-.125	1.902	.522
-.150	1.910	.510
-.175	1.177	.404
-.200	.402	.302
-.225	-.357	.166
-.250	-1.193	.262
-.275	-2.061	.398
-.300	-3.004	.624
-.325	-4.260	1.223
-.350	-8.044	1.321
-.375	-12.160	3.480
-.400	-14.800	2.175
-.425	-20.370	3.380
-.450	-26.430	4.050
-.475	-34.120	5.710
-.500	-44.460	7.680
-.525	-57.060	11.790
-.550	-69.220	14.020
-.575	-84.400	18.240
-.600	-108.200	39.000
	<u>Mean</u>	<u>Std. Dev.</u>
$E_{\text{corr}}$ (V vs SCE)	-.211	.001



TABLE XXXI

STAINLESS STEEL IN SEAWATER TREATED WITH 8.49 ml CLOROX

Potential (V vs SCE)	Current Density ( $\mu\text{A}/\text{cm}^2$ )	
	Mean	Std. Dev.
.525	43560.000	5180.000
.500	35600.000	4180.000
.475	28090.000	5410.000
.450	22210.000	4640.000
.425	16010.000	7360.000
.400	8595.000	5749.000
.375	3833.000	2861.000
.350	1932.000	976.000
.325	1309.000	852.000
.300	706.500	575.800
.275	307.400	311.600
.250	160.000	133.800
.225	121.200	149.600
.200	96.620	128.500
.175	81.120	117.400
.150	56.630	100.000
.125	5.661	12.680
.100	-1.650	9.140
.075	-6.782	5.526
.050	-8.086	4.597
.025	-12.300	5.150
.000	-15.420	5.320
-.025	-18.780	7.600
-.050	-25.750	10.320
-.075	-24.460	12.490
-.100	-42.190	13.920
-.125	-50.930	16.050
-.150	-59.570	16.590
-.175	-67.350	18.620
-.200	-74.790	19.870
-.225	-79.910	20.340
-.250	-84.790	20.700
	Mean	Std. Dev.
$E_{\text{corr}}$ (V vs SCE)	.125	.032
$[\text{OCl}^-]$ ppm	99.310	1.150



TABLE XXXII

ALUMINUM ALLOY IN UNTREATED SEAWATER

Potential (V vs SCE)	Current Density ( $\mu\text{A}/\text{cm}^2$ )	
	<u>Mean</u>	<u>Std. Dev.</u>
-.400	54160.000	6967.000
-.425	51230.000	8142.000
-.450	46810.000	5906.000
-.475	42930.000	4506.000
-.500	38560.000	3480.000
-.525	34930.000	3198.000
-.550	31640.000	2374.000
-.575	27670.000	1762.000
-.600	23380.000	4070.000
-.625	17710.000	3810.000
-.650	13860.000	2047.000
-.675	10580.000	1741.000
-.700	7330.000	728.800
-.725	4754.000	813.400
-.750	2321.000	1079.000
-.775	358.700	88.300
-.800	-54.770	9.390
-.825	-65.980	12.830
-.850	-72.700	11.520
-.875	-76.740	9.210
-.900	-82.450	8.550
-.925	-88.150	7.340
-.950	-90.890	7.170
-.975	-96.340	5.620
-1.000	-101.500	5.400
-1.025	-106.100	6.500
-1.050	-111.200	8.500
-1.075	-116.800	11.200
-1.100	-122.300	14.300
-1.125	-128.100	18.000
-1.150	-138.300	29.000
-1.175	-146.000	37.000
-1.200	-152.200	44.600
-1.225	-155.300	43.900
	<u>Mean</u>	<u>Std. Dev.</u>
$E_{\text{corr}}$ (V vs SCE)	-.793	.005





TABLE XXXIII

ALUMINUM ALLOY IN SEAWATER TREATED WITH 8.40 ml CLOROX

Potential (V vs SCE)	Current Density ( $\mu\text{A}/\text{cm}^2$ )	
	Mean	Std. Dev.
-.375	96340.000	19210.000
-.400	39350.000	17060.000
-.425	82480.000	16370.000
-.450	75610.000	16450.000
-.475	69280.000	15480.000
-.500	62210.000	15620.000
-.525	53440.000	14440.000
-.550	46470.000	14400.000
-.575	38300.000	11260.000
-.600	32770.000	10100.000
-.625	27090.000	7750.000
-.650	20020.000	8640.000
-.675	12010.000	5640.000
-.700	4677.000	2274.000
-.725	2086.000	1461.000
-.750	312.700	334.500
-.775	-13.450	8.970
-.800	-19.080	9.020
-.825	-22.730	10.850
-.850	-22.240	9.150
-.875	-23.730	9.020
-.900	-26.250	9.170
-.925	-28.970	9.360
-.950	-30.890	9.300
-.975	-33.940	8.820
-1.000	-38.450	9.680
-1.025	-41.170	10.360
-1.050	-46.940	11.360
-1.075	-52.440	12.010
-1.100	-59.940	12.570
-1.125	-66.970	12.330
-1.150	-76.600	10.170
-1.175	-87.670	12.170
-1.200	-102.900	11.310
-1.225	-118.100	8.900
	<u>Mean</u>	<u>Std. Dev.</u>
$E_{\text{corr}}$ (v vs SCE)	-.757	.007
$[\text{OCl}^-]$ ppm	96.820	7.380



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